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THE UNIVERSITY OF WISCONSIN
COLLEGE OF ENGINEERING

REVISED STEAM AND GAS ENGINEERING LABORATORY NOTES

BY

W. BLACK
Assistant Professor of Steam Engineering

G. L. LARSON
Associate Professor of Steam Engineering

O. L. KOWALKE
Associate Professor of Chemical Engineering

AND

P. H. HYLAND
Instructor of Machine Design

THIRD EDITION, REWRITTEN AND ENLARGED

MADISON, WISCONSIN
1916

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PREFACE TO THE THIRD EDITION

It is the policy of the Engineering Department of the University of Wisconsin to coordinate, to as great an extent as possible, the class and laboratory work of all the courses. The classroom work covers the theoretical treatment of the design of machinery, thermodynamics and fuels. It also deals with the application of theory to practical machines, and with the principles of the machines themselves, using as examples, when possible, the apparatus in the laboratories. Therefore, this book of "Steam and Gas Engineering Laboratory Notes" does not discuss theory or principles of machines or instruments further than to emphasize certain features which apply particularly to the work in the laboratory. When further information on some subject is considered desirable, special short lecture courses are given to accompany the laboratory work. While the directions for carrying out the experiments are sufficiently definite for the purpose, they are not so specific that the student cannot develop originality in this work.

The chapters on the Balance, Fuel and Gas Analysis and Pyrometers have been added by Professor Kowalke to the original notes.

For fuller discussion of experimental work than is given in this text, reference can be made to the following excellent books which were frequently consulted in the preparation of these notes:

Experimental Engineering, Carpenter & Diederichs.

Power Plant Testing, Moyer.

Testing of Motive Power Engines, Royds.

The Testing of Engines, Boilers and Auxiliary Machinery, Pullen.

Mechanical Engineer's Pocket Book, Kent, the *Transactions of the American Society of Mechanical Engineers* and the *A. S. M. E. Power Test Code.*

The authors desire to express their thanks for valuable assistance in the preparation of this edition to Messrs. A. E. Berggren, A. H. Aagaard, and A. S. Romig, Instructors in Steam and Gas Engineering, who prepared, wholly or in part, many of the experiments in this book. The authors wish to give special thanks to Professor A. G. Christie, Associate Professor of Mechanical Engineering, Johns

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Hopkins University, who edited the first two editions of this book and who assisted in the revision and proof reading of this edition, also to W. J. Dana, Instructor in Mechanical Engineering, Johns Hopkins University.

The Authors.

Madison, August 20, 1916.

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STEAM AND GAS ENGINEERING LABORATORY NOTES

GENERAL DIRECTIONS FOR WRITING REPORTS

In connection with the work of the Steam and Gas Engineering Laboratory, two reports will be required of each student, one, a preliminary report and the other, a final report.

The schedule of assignments will be posted in the laboratory at the beginning of each semester. The experiment number under each name corresponds to the number of the experiment in the table of contents of this book. New experiments will be given a new number and both name and number will be posted on the board.

The month and day of the month on which the experiment is to be performed are shown on the margin.

The preliminary report must be handed in before the experiment is to be performed according to the schedule posted in the laboratory. The instructor in charge of the section will inform his students when he wishes the preliminary report handed in. This report must state fully and clearly the object and method of conducting the experiment and must include a statement of the tools, instruments, measuring tanks, etc., required for the experiment. This report will be returned to the student by the instructor on the day of the experiment and must be included in his final report. No student will be allowed to make an experiment until his preliminary report has been accepted unless specially excused.

The preliminary report must also include blank tabulation forms on which the original data can be copied on completion of the experiment in the laboratory. Carbon copies of all data may be made in some tests but each student must see that he gets a copy before leaving the laboratory.

The final report is due the first week following the performance of the experiment. The instructor will look over this report within a week, when it should be called for and corrections made if necessary. Reports returned for correction are again due in one week. Ten per

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cent will be deducted for tardy reports for each week or fraction of a week unless excuse be given by the instructor.

Put reports in the case in the laboratory. Reports are to be written on standard laboratory note paper (M 3) size 8½ by 11 inches and must be bound in standard "College of Engineering" brown Manila covers. For tabulating data the ruled form (M 3) for sale at the Co-op and at the University Supply Association is advised. For plotting curves use standard co-ordinate paper of 20 lines to the inch. Where reports are typewritten use plain unruled paper.

When two or more students work together on an experiment, it is permissible that they work it up together. But each student must hand in a separate report which is complete in itself, and independent of any report handed in by his partner.

Special emphasis will be laid on making reports according to the best methods in commercial practice. The reports must be full and clear, and yet concise. They must be neatly written in ink with words properly spelled and sentences grammatically correct. The different steps of the experiment must be explained in a logical manner. All data must be neatly tabulated. The student should consider that he has been sent by a party to report on some experiment or test and should write his report in such a way as to give his employer, on reading this report, a clear idea of the experiment. The presentation of all observed data is absolutely necessary to enable the employer to check results. This is the sort of report required when the graduate enters the practice of his profession.

THE SEMESTER'S CREDIT WILL BE BASED ON THE PERFORMANCE OF AND THE REPORT ON THE NUMBER OF EXPERIMENTS ON THE SCHEDULE, EACH SECTION IN ANY COURSE BEING REQUIRED TO COMPLETE THESE UNLESS SPECIALLY EXCUSED. Should a student fail to take some experiment at the assigned time, he should see his instructor at once and arrange to take it with some other section as it will be necessary to make up this work for credit.

THE FINAL STANDING OF EACH STUDENT WILL BE BASED ON (a) PRELIMINARY REPORT (b) PRACTICAL LABORATORY WORK (c) COMPLETED REPORT. ON THE COMPLETED REPORT 15 PER CENT OF THE CREDIT IS ALLOWED FOR GENERAL FORM AND NEATNESS.

The final report should include the preliminary report and should describe all apparatus and instruments used, show the principles of the construction and operation of the apparatus used and its arrangement. This is often facilitated by means of a neat diagrammatical sketch.

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Sample numerical computations must be given in the final report of all items called for in the general report of each test. Errors can then more easily be found out and corrected. If several tests are made at different loads, the sample computations need only be made for one of these loads. THIS IS MOST IMPORTANT AND WILL BE ESPECIALLY EMPHASIZED IN ALL CASES.

If the instruments have been calibrated, give the corrections found.

State clearly the conditions under which the experiment was performed and how the instruments were used and read.

Include all important dimensions and constants for all apparatus used and present all data according to forms shown with each experiment. In advanced work where no forms are provided the student should be able to make up his own data sheet.

The general results must also be presented in the form shown for each experiment.

Whenever possible, present results in the form of a curve or set of curves locating the points by $\frac{3}{32}''$ circles. Letter and make clear the title of the curve and the scales of the coordinate axes. The report should show the conclusions the student would draw from the results of his experiments, how these compare with theoretical results and also with the average results of good practice.

When steam tables are used in the working up of an experiment, those given in Goodenough's *Properties of Steam and Ammonia*, in general should be used. If Marks and Davis' tables or those of any other author are used this fact should be noted in the report.

When indicator cards are taken include sample cards from each indicator in your final report.

The original data sheet taken in making any experiment in the laboratory must be handed to the instructor in charge at the end of the laboratory period in which the experiment is performed. Copies must be made of this original data and must accompany the reports submitted for credit in the forms shown for each experiment. If desired, carbon sheets may be used to make these duplicates.

One of the secondary objects of this laboratory work is to make the student realize the sources and probability of errors in experimental tests. THESE SHOULD BE COMMENTED UPON IN THE FINAL REPORT, ESPECIALLY WHERE RESULTS ARE ABNORMAL IN ANY WAY.

The following is a suggested outline for reports which may be varied to suit the different experiments:

(1) Object of the experiment.

(2) Description of the apparatus, including sketches when called for.

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(3) Method of conducting the experiment.
(4) Formulae used and sample computations.
(5) Results and conclusions.
(6) Curves when called for.
(7) Sample indicator cards when taken.
(8) Data sheets

All reports are filed away in offices of the laboratory and are returned to the students shortly before graduation.

SUGGESTIONS ON WRITING REPORTS

In this Laboratory Manual it has been the aim of the authors to make everything as complete as possible in order that the book may be used by the students as a guide in conducting commercial tests after they graduate. In a great many experiments in the Steam Laboratory it will not be necessary to take as full data or work up as complete a set of results as is indicated. Wherever this is so the instructor in charge of the section will inform the students just what is required.

Accuracy in mathematical computations will be emphasized throughout all laboratory courses, for the results of a test are absolutely worthless if the computations are incorrect. Whenever possible, the slide rule should be used to save time as it is possible to read this with less than 1 per cent error.

When it is necessary to plot curves to show the relation between two given variables, select one as abscissae and select suitable scales by which to plot both variables. The cross-section paper has 20 divisions to the inch. A suitable scale may be defined as one which is a simple factor or multiple of 20 such as 1, 2, 5, 10, 20, 40, etc., parts to the inch. Such scales as 3, 6, 7, 9, 11, etc., are *not* convenient to use on such cross-section paper. When the scale is selected, mark opposite each inch the quantity it represents on the chosen scale and write under these figures the title of the variable which the scale represents. When the points are plotted, draw a smooth even curve through the average of these points, or if the diagram is to show variations in conditions as in a log of a boiler test, connect the actual points plotted by straight lines. When a number of curves are plotted on the same sheet, name each curve. This is preferable to numbering them and referring these numbers to a table.

Electrical, chemical, and mechanical engineers are advised to provide themselves with a Mollier Heat Diagram and a set of steam

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tables, or the tables in a textbook on heat engines may be used. This heat diagram is plotted with entropy and total heat as the two co-ordinates. There are lines of constant absolute pressure, lines of constant quality, the saturation line, and lines of temperature or superheat.

The student will find that much of the work of writing reports can be lessened by taking a few sheets of cross-section paper and plotting out a number of relations that are used continuously. The most frequent one is the conversion of inches of mercury into pounds per sq. in. pressure as in barometer and barometer plus back pressure in calorimeter readings. If a curve is plotted to a large scale between 28 in. and 35 in. of mercury and pounds pressure, almost all usual observations can readily be changed into pounds per sq. in. absolute. There are a number of other curves which can also be used to great advantage, such as brake horsepower curves, inches of water to pounds pressure, etc.

The last page of Goodenough's tables on the *Properties of Steam and Ammonia* contains three tables for the conversion of pressure, energy, and power from one system of measurement to another. It would be of great value to the student to become thoroughly familiar with this table as it is one of the most complete of its kind.

Useful Information

The brake horsepower of a prony brake is found by the following formula

$$\text{br.h.p.} = \frac{2\pi rNW}{33000}$$

where r = length of the brake arm in feet.
N = r.p.m.
W = Net weight on the scales in pounds.
1 in. of mercury = 0.491 lb. per sq. in.
= 1.132 ft. of water at 62° F.

The specific gravity of mercury is 13.6.

The weights of a cu. ft. of water at varying temperatures will be found in Kent's *Mechanical Engineer's Pocket Book*. At ordinary laboratory temperature 1 cu. ft. of water weighs approximately 62.3 pounds.

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STANDARDS

Taken from the 1915 *Power Test Code* of the American Society of Mechanical Engineers.

DEFINITION OF UNITS

One British thermal unit, or heat unit as herein used = 1/180 of the heat required to raise 1 lb. of water from 32 deg. to 212 deg. fahr.

One unit of evaporation (U. E.) = heat required to evaporate 1 lb. of water at 212 deg. into steam at the same temperature = 970.4 British thermal units.

One foot-pound = work done by 1 lb. force acting through 1 ft.

One pound (of force) = the force exerted by gravity on 1 lb. of matter where the acceleration due to gravity is 32.1740 ft. per second per second; that is, (very nearly) the force of gravity on 1 lb. of matter at latitude 45 deg. at the sea level.

Mechanical equivalent of heat: 1 B.t.u. = 777.54 ft-lb. or 1 ft-lb. = 0.0012861 B.t.u.*

One horsepower = 33,000 ft-lb. per min. = 550 ft-lb. per sec.
= 1,980,000 ft-lb. per hour.
= 2,546.5 B.t.u. per hour = 42.44 B.t.u. per min.
= 745.7 watts = 0.7457 kilowatts.*

One kilowatt = 1000 watts = 1.3410 h.p. = 3,415 B.t.u. per hour = 737.56 ft-lb. per sec.

One kilowatt-hour = 1.3410 h.p.-hr. = 2,655,200 ft-lb.

One U. S. gallon = 231 cu. in.

One atmosphere = 760 m.m. or 29.921 in. of mercury at 32 deg. fahr.
= 29.951 in. of mercury at 62 deg.** fahr.
= 14.6963 lb. per sq. in.

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* Based on the following accepted values:—
1 mean calorie=4.1834 ×107 dyne-centimeters (Marks & Davis)
1 dyne= $\frac{1 \text{ gram}}{980.665}$ (International Standard). 1 c.m.= $\frac{0.3937}{12}$ ft.
1 B.t.u.=1.8 lb-deg. cent. 1 gram=.002204622 lb.
1 watt=10.7 dyne-centimeters per sec.=0.73756046 ft. -lb. per sec.
1 h.p.=550 ft. lb. per sec.= $\frac{550}{0.73756046}$ =745.702 watts.

** At latitude 45 deg. at sea level the density of mercury at 32 deg. is 13.59545 grams per cu. m. Linear expansion of mercury 0.0000333 per deg. Fahr.

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STANDARD UNITS OF CAPACITY

a Boilers*	One pound of water evaporated into dry steam from and at 212 deg. per hour
b Reciprocating Steam Engines	One indicated horsepower developed in the main cylinders
	One brake horsepower delivered by the main shaft
c Steam Turbines	One brake horsepower delivered by the main shaft
d Turbo-generators, (including engine-driven generators)	One kilowatt delivered at the generator terminals,† not including kilowatts used by exciter‡
e Pumping Machinery	One gallon of water discharged to the force main in 24 hr.
	One gallon of water discharged per min.§
	One water hosepower delivered to the force main, based on the total head including suction
f Compressors, Blowers, and Fans	One cu. ft. of air at 62 deg. and 30 in.¶
	One air horsepower
g Locomotives	One indicated horsepower developed in the main cylinders
	One dynamometer horsepower delivered to the draw-bar
h Gas Producers	One pound of dry fuel of given quality consumed per hour
	One cu. ft. per hour of dry gas having a stated quality at 60 deg. and 30 in.
i Gas and Oil Engines	One brake horsepower delivered by the main shaft
	One indicated horsepower developed in the engine cylinder
	One brake horsepower delivered by the main shaft
j Waterwheels	One kilowatt delivered at the generator terminals,† not including kilowatts used by exciter‡

* A subsidiary unit which may be used for stationary boilers is a "Boiler Horsepower," or 34½ lb. of water evaporated from and at 212 deg. per hour, i. e., from water at 212 deg. into steam at the same temperature. The unit called "Myriawatt" has been suggested by some engineers as a unit of boiler capacity. It is 2 per cent greater than the "boiler horsepower" and is equivalent to 34,150 heat units per hour, the "boiler horsepower" being 33,479 heat units per hour.

† If switchboard instruments are used for the electrical measurements, correction should be made for the drop in voltage between generator and switchboard, unless the drop is so small as to be negligible.

‡ If the exciter current is taken from an outside source the kw. thus supplied including field rheostat losses are to be deducted from the total output. Likewise the kw. used by separately driven ventilating fan.

§ This unit applies to small pumps and some classes of large sized pumps.

¶ 30 in. mercury barometer refers in round numbers to a standard atmosphere with mercury at an ordinary temperature, of say 78 deg., which is equivalent to 29.921 in. at 32 deg.

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STANDARDS OF EFFICIENCY AND ECONOMY

a Boilers	Relation between B.t.u. absorbed by boiler per lb. of dry coal and calorific value of 1 lb. dry coal. (Efficiency of boiler furnace and grate.)
	Relation between B.t.u. absorbed by boiler, per lb. of combustible burned and calorific value of 1 lb. combustible. (Efficiency based on combustible.)
b Reciprocating Steam Engines	(1) B.t.u. per i.h.p-hr.
	(2) B.t.u. per brake h.p-hr.
	(3) Ft-lb. of net work per B.t.u.
	(4) Thermal efficiency referred to i.h.p.
	(5) Thermal efficiency referred to br.h.p.
	(6) Rankine cycle ratio referred to i.h.p.
	(7) Rankine cycle ratio referred to br.h.p.
	(8) Lb. of steam per i.h.p-hr.
	(9) Lb. of steam per br.h.p-hr.
c Steam Turbines	(1) B.t.u. per br. h.p-hr.
	(2) Ft-lb. of net work per B.t.u.
	(3) Thermal efficiency.
	(4) Rankine cycle ratio.
	(5) Lb. of steam per br.h.p-hr.

NOTE:—The term "steam" means dry steam, either saturated or superheated as the case may be. If it contains moisture, the moisture is to be deducted. If superheated, no correction is to be made.

d Turbo-generators, (including engine-driven generators)	(1) B.t.u. per kw-hr.
	(2) Ft-lb. of net work per B.t.u.
	(3) Thermal efficiency.
	(4) Rankine cycle ratio.
	(5) Lb. of steam per kw-hr.
e Pumping Engines	(1) Ft-lb. of work per million B.t.u.
	(2) Ft-lb. of net work per B.t.u.
f Compressors, Blowers, and Fans	(1) B.t.u. per net air h.p-hr.
	(2) Ft-lb. of net work per B.t.u.
	(3) Lb. of steam per net air h.p-hr.
	(4) Lb. of steam per 1000 cu. ft. of free air compressed to 100 lb. gage pressure reduced to atmospheric temperature.
g Complete Steam Power Plants:	
Plants in General	(1) Lb. of coal as fired per i.h.p-hr.
	(2) Lb. of steam per i.h.p-hr.
	(3) Heat units in fuel consumed per i.h.p-hr.
Electric Plants	(1) Lb. of coal as fired per kw-hr.
	(2) Lb. of steam per kw-hr.
	(3) Heat units in fuel consumed per kw-hr.
Pumping Plants	(1) Ft-lb. of work per million B.t.u.
	(2) Lb. of coal as fired per water h.p-hr.
Air Machinery Plants	(1) Lb. of coal as fired per air h.p-hr.
	(2) Lb. of steam per air h.p-hr.

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h Locomotives	(1) Lb. of coal as fired per i.h.p-hr. (2) Lb. of coal as fired per dyn. h.p-hr. (3) Lb. of steam per i.h.p-hr. (4) Lb. of steam per dyn. h.p-hr. (5) Lb. of coal as fired per ton-mile.
i Gas Producers	Relation between B.t.u. of the gas output per lb. of dry fuel and calorific value of 1 lb. of dry fuel.

NOTE:—The i.h.p. and brake h.p. in this table refer to that of the main engine, turbine, or water wheel, and the kw. to the power measured at the generator terminals, not including exciter output.

j Gas and Oil Engines	(1) B.t.u. per i.h.p-hr. (2) B.t.u. per br. h.p-hr. (3) Ft-lb. of net work per B.t.u. (4) Thermal efficiency referred to i.h.p. (5) Thermal efficiency referred to br. h.p. (6) Lb. of oil per i.h.p-hr. (7) Lb. of oil per br. h.p-hr. (8) Cu. ft. of dry gas at 60 deg. and 30 in. per i.h.p-hr. (9) Cu. ft. of dry gas at 60 deg. and 30 in. per br. h.p-hr.
k Waterwheels	(1) Relation between brake h.p. and potential h.p. of total water used. (2) Relation between kw-hr. delivered and potential kw-hr.

The English Standards used in Tables 4 to 6 may be converted into metric units (and vice versa) by the use of the following factors:

Factors for Converting English Units to Metric Units.

One inch	= 2.54	centimeters
One foot	= 0.3048	meter
One sq. in.	= 6.4516	sq. cm.
One cu. ft.	= 0.028317	cubic meter
One U. S. gallon	= 3.7854	liters
One pound	= 0.453592	kilogram
One lb. per sq. in.	= 0.070307	kg. per sq. cm.
One foot-pound	= 0.13826	meter-kilogram
One horsepower	= 1.0139	cheval-vapeur
One B.t.u.	= 0.252	kilogram-calorie
One deg. Fahr.	= 0.55556	deg. centigrade

Factors for Converting Metric Units to English Units.

One centimeter	= 0.3937	inch
One meter	= 3.28083	feet
One sq. cm.	= 0.155	sq. in.
One cubic meter	=35.3145	cu. ft.
One liter	= 0.26417	U. S. gallon
One kilogram	= 2.20462	pounds
One kg. per sq. cm.	=14.223	lb. per sq. in.

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One meter-kilogram	= 7.233	foot-pound
One cheval-vapeur	= 0.98629	horsepower
One kilogram-calorie	= 3.9683	B.t.u.
One deg. centigrade	= 1.8	deg. Fahr.

The "calorific value" of fuel is the number of heat units developed in completely burning one pound of the fuel including the heat contained in any water vapor formed through burning the hydrogen component. This is the higher heat value and not the so-called net or available heat value, in obtaining which the latent heat in the vapor thus formed is deducted.

THE DEFINITIONS OF EFFICIENCY

Wherever the Rankine cycle is referred to in this text the practice of the American Society of Mechanical Engineers in defining the Rankine cycle as the complete expansion cycle has been followed.

The following expressions of efficiency have been adopted by the Steam and Gas Engineering Department for use in class and laboratory work. These are the expressions more commonly used in the experimental work. Where expressions of efficiency apply to only one particular machine, a statement of this ratio will be found in the description of the experiment.

The thermodynamic efficiency of the ideal engine working on the Carnot cycle is

$$E_c = \frac{T_1 - T_2}{T_1}$$

where T_1 and T_2 are the maximum and minimum absolute temperatures of the cycle.

Thermal efficiency of a steam engine

$$E_T = \frac{\text{Heat utilized in i.h.p.}}{\text{Heat supplied above the heat of the liquid at exhaust pressure}}$$

$$= \frac{\text{i.h.p.} \times 2546.5}{W\,(x_1 r_1 + q_1 - q_2)}$$

where W = total pounds of wet steam supplied per hour.
x_1 = quality of the steam entering the engine.
r_1 = latent heat of the steam entering the engine.
q_1 = heat of the liquid of the steam entering the engine.
q_2 = heat of the liquid at the exhaust pressure.

Thermal efficiency of a gas engine

$$E'_T = \frac{\text{Heat utilized in work}}{\text{Heat supplied above engine room temperature}}$$

$$= \frac{\text{h.p.} \times 2546.5}{Q_1} \quad \text{Use i.h.p. where possible.}$$

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where Q_1 = heat supplied in fuel above engine room temperature.

B.t.u. per i.h.p-hr. = pounds of wet steam per i.h.p-hr. ($x_1 r_1 + q_1 - q_2$)

The efficiency ratio of an engine referred to a Rankine cycle is defined as

$$E_R = \frac{\text{Heat utilized in work per lb. of steam}}{\text{Heat available per pound of steam by expansion from the initial conditions on a Rankine cycle to the exhaust pressure}}$$

The denominator of this expression can easily be found by the use of a Mollier chart.

THE HANDLING OF INSTRUMENTS AND APPARATUS

Should any piece of apparatus be broken, the fact should be reported at once to the instructor in charge so that repairs can be made.

When breakage occurs due to gross carelessness or neglect on the part of a student, he will be held responsible for the damage.

It is advisable that each student coming into the laboratory provide himself with a slide rule, a watch with a second hand, a 6 in. flexible steel rule divided into 64ths and 100ths of an inch and a speed counter.

When returning instruments to the cases, see that they are thoroughly cleaned and properly put away.

When testing steam engines, always see that the water is turned onto the condenser before starting up and turned off again when the test is completed. With internal combustion engines, see that there is sufficient water flowing through the jackets at all times. Watch oil cups and lubricators closely on all apparatus to obtain constant results and to avoid trouble.

If it is necessary to read the barometer in the laboratory, first adjust the screw on the bottom till the ivory point is just flush with the surface of the mercury. Then adjust the upper slider until its lower edge just touches the top of the meniscus of the mercury. The reading on the vernier then gives the barometer height. The temperature of the column should also be read in accurate work.

Use care in handling the tubs in the laboratory as it is easy to start these leaking and then the results of the tests become subject to error.

The platform scales used for weighing condensed steam, brake loads, etc., should be placed level and the beam should balance with no load on the platform,

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GENERAL INSTRUCTIONS

In all experiments where four or more students work in a group, one of the number appointed by the instructor in charge will act as chief engineer in charge of the party. It will be his duty to make out all necessary data sheets beforehand, become thoroughly familiar with the experiment and place all men at the different stations for taking readings. It will be his duty to see that each member of the party gets the necessary data to work up the test, hand in a set of data to the instructor, and see that all apparatus is cleaned up and put away in its proper place. On each experiment the man to be in charge of that particular experiment will be indicated on the bulletin board in the laboratory by a red check mark.

EXPERIMENT NO. 1

CALIBRATION OF STEAM AND VACUUM GAGES AND THERMOMETERS

In "Tables of the Properties of Saturated Steam," there are columns showing the temperatures, in degrees F., corresponding to given absolute pressures. The relation of temperature and pressure is fixed so long as the steam is in a moist or saturated condition. When the temperature is greater than that shown in the tables, the steam is said to be superheated.

The experiment consists of studying the construction of instruments for measuring both temperature and pressure and the methods of calibrating these instruments, and of determining by experiment the relations shown in the steam tables between temperature and absolute pressures.

A pressure can be measured by noting the difference in height of a liquid in a U tube, one end of which is exposed to the pressure and the other open to the atmosphere. This method is used where vacuum or pressures of only a few pounds are to be measured. Pure mercury is the usual liquid though water is employed in boiler draft gages.

Pressures are usually measured by means of pressure gages. One type of gage depends on the expansion under pressure of a small metal diaphragm which through a suitable mechanism moves a

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pointer over a dial which is graduated to indicate pressure in lb. per sq. in.

The more common type is the Bourdon gage. The pressure is exerted on the interior of a curved tube, oval in cross section, with one side partially flattened. This tube is bent to fit the interior of a circular case. As the free end is closed, the application of pressure tends to make the cross section round and thus to straighten the tube. The motion of this free end is communicated by means of levers and rack and pinion to a spindle carrying a pointer which revolves over a graduated scale on the face of the gage. A small hair spring on the pinion spindle takes up the lost motion in the connections and tends to prevent vibration of the pointer.

In this experiment remove the pointer by a special jack for this purpose and take off the dial. Sketch the arrangement of the parts in the interior of the gage.

It is bad practice to allow steam or highly heated water to pass into the bent tube of the gage as the increased temperature will cause false indications on the dial and it also injures the metal of the tube by causing it to assume a permanent deformation. Hence there should always be provided a condensing pipe or siphon between the steam gage and its connection to the steam supply. This collects the water of condensation and thus seals off the hot steam. This siphon may be U shape or may consist of coils about 2½ in. diameter of small pipe. With superheat, coils of ¼ in. copper tubing are recommended.

The best working pressure for a gage is from ½ to ⅔ its maximum graduation. This is important and should be kept in mind in using steam gages.

Temperatures are usually measured in one of several ways, (1) by mercurial thermometers, (2) by resistance thermometers, (3) by thermocouples. Other devices less commonly used are air thermometers, calorimetric devices, etc. Mercurial thermometers are based on the expansion under heat of mercury in a glass bulb and capillary tube. These, when subjected to steam temperatures, are liable to errors from such causes as variable diameter of bore and permanent change of the glass bulb. Hence it is necessary to calibrate them frequently.

The following rules for handling and using mercurial thermometers should be observed closely:

1. Keep the thermometer in its case when not in use.
2. Exercise care in inserting and removing the thermometer from

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its well. If the temperature is high, gradually warm up the thermometer before placing it in the well.

3. See that there is no water in the well before inserting the thermometer, as it will explode when heated.

4. Keep the well filled with heavy oil or mercury and wrap the thermometer stem with waste at the mouth of the well to avoid contact with the metal.

5. Be sure that the range of the thermometer is high enough for the temperature to which it will be exposed.

6. Do not carry the thermometers wrong end up.

7. Return the thermometer to its own case after using and replace case in the racks.

Recording thermometers are made with a large metal bulb filled with mercury, alcohol, or ether and connected by a capillary metal pipe to the curved tube of a Bourdon gage. Any increase in temperature at the bulb produces a rise in pressure which moves the recording finger over the recording disc on the face of the gage. These instruments require frequent calibration.

The resistance thermometer is based on the increase in resistance of a fine platinum wire when the temperature is increased. This increase can be measured either on a Wheatstone bridge or one of its modifications provided with dials, on which the temperature can be read directly.

Temperatures may be measured by thermocouples which consist of a joint of two wires having different thermoelectric properties, such as platinum and an alloy of platinum and iridium. The joint when heated generates an electric current which is proportional to the temperature and which can be measured by a sensitive galvanometer. This instrument must be calibrated at known temperatures.

Vacuum is sometimes indicated by a Bourdon gage which is subject to the same inaccuracies as when used under pressure. It is advisable, especially with high vacuum, always to use a mercury column. Vacuum is usually measured in inches of mercury equivalent to the difference of pressure between the atmosphere and the chamber to which the gage is attached.

When mercury is used in vacuum columns it is essential that it shall be chemically pure and free from alloys if correct results are desired. The temperature of the mercury column should also be recorded as mercury and glass expand at a different rate. This correction amounts to .000088 in. per degree Fahrenheit per inch

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length of column but only need be applied in accurate work. The capillary action of the glass tube must also be corrected for, in accurate work. This force depresses the mercury in the tube. The amount of this depression increases rapidly as the bore of the tube decreases. Values for this correction when such need be applied, can be found in Moyer's *Power Plant Testing*, page 4, or in Carpenter's *Experimental Engineering*.

The specific gravity of mercury is 13.6 and a column one in. high will exert a pressure of 0.491 lb. per sq. in.

Calibrations

Pressure gages may be calibrated in several ways:

1. By comparison with a Mercury Column which must be of considerable height for ordinary steam gages. When the temperature of the mercury is allowed for, very accurate results can be obtained.

2. By comparison with an accurate standard gage. Both gages are connected to the same source of pressure and their readings compared for various pressures. This method is fairly accurate and may be followed when no other means is at hand.

Boiler inspectors usually calibrate gages by this method.

3. The commonest method in engineering is by the use of the dead weight tester, which gives very accurate results.

Fig. 1 shows the principles of a Crosby gage tester. It consists of a chamber (a) filled with sperm oil or, preferably, glycerine. A gage (b) is attached to one part of this chamber, which also connects with a cylinder (c) having a smooth bore fitted with a piston of one-fifth square inch cross-sectional area. The piston (d) carries a platform (e) upon which accurate known weights may be placed. The platform and piston weighs one lb. and requires therefore a pressure of 5 lb. per sq. in. to sustain it. In communication with the oil chamber referred to is a reservoir (f) fitted with an adjusting plunger which is operated by the hand wheel shown to the right. This is used to force oil through the system as occasion demands in order to keep the platform and weights floating. (g) is a three way cock to drain the gage.

To Calibrate a Gage.—Fit it in place, open the cock (g) which connects it with the piston chamber. Screw in the plunger until the platform has risen about 2 in. above its lowest position. Spin the platform to avoid error due to piston friction and take a reading of the gage. Add weight to the platform by 5 lb. steps until the limit of the gage is reached, taking readings of the gage for every step.

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Then reduce the pressure by 5 lb. steps. Record these readings in a form as shown with these instructions, both when adding weight and when taking off weight. Should the gage show a considerable error, remove the pointer and reset it to read correctly.

Calibration of Vacuum Gage.—The gage to be tested is compared with the height of a column of mercury, the vacuum being produced by a small aspirator or ejector. Readings are taken for every 5 in. change in vacuum, both increasing and decreasing. Record read-

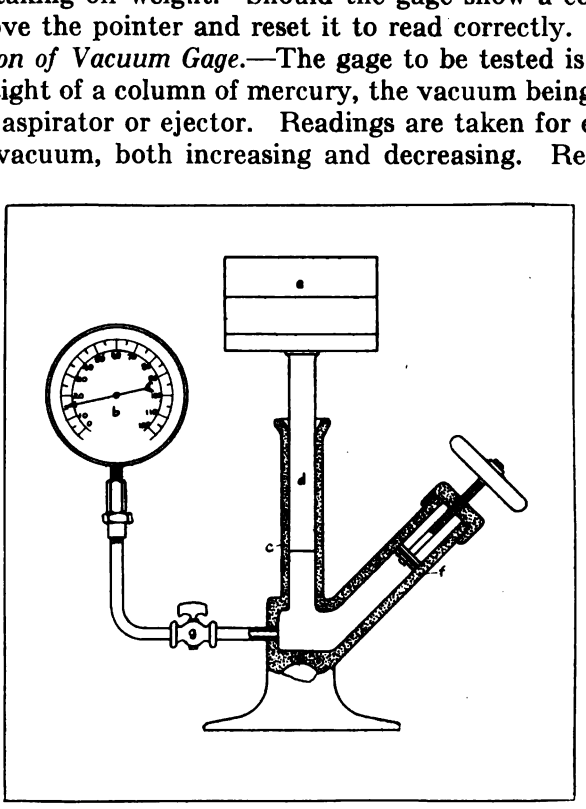

FIG. 1. GAGE TESTER

ings in form as shown. The absolute pressure is equal to the difference between the barometer and the vacuum either in in. of mercury or equivalent lbs. pressure.

Calibration of Thermometers.—Thermometers may be calibrated by comparison with a standard thermometer in a water or oil bath or by exposing them to heat at some fixed temperature, such as melting ice, or moist steam at atmospheric pressure.

When possible, thermometers should be immersed in the liquid in the well until the level of the mercury of the thermometer just shows above the cup.

In accurate temperature measurement a correction must be applied to the thermometer for the stem exposure of the column above

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the liquid in the well. The method of making this correction will be found in Meyer's *Power Plant Testing*, p. 31.

In engineering work, temperatures usually exceed that of moist steam at atmospheric pressure. An accurate method of calibration for such higher temperatures is to place the thermometer in a well, fitted in a vessel containing moist steam at some known pressure. When conditions become constant, read the temperature, pressure, and barometer, and compare the observed temperature with that given in the steam tables for the observed absolute pressure. Perform this calibration by attaching the steam gage that has just been calibrated to a chamber in which a number of thermometers are inserted. Allow this chamber to fill with moist steam and after conditions become normal, read the pressure, temperature, and barometer. Vary the steam pressure and wait about five minutes until the pressure is constant before taking readings. Care must be taken that the steam is moist and not superheated, by allowing a certain amount of water to remain in the bottom of the vessel.

Calibrate the thermometers for increasing pressures only.

Record the observations in a form as shown below. The pressures given in the steam table are absolute and hence the barometric pressure must be added to the gage pressure before using the tables.

Next immerse a thermometer at varying depths in its cup and note the change in temperature should such occur.

Clean up all apparatus when you are through and place it in its case or cupboard.

For instructions in adjusting the multiplying arrangement in the gages the student is referred to manufacturers' catalogs.

DIRECTIONS FOR TEST

Examine a pressure gage and calibrate it with a Crosby gage tester, first setting the pointer to read correct at 100 lb. per sq. in. and then taking readings at 10 lb. intervals, starting at zero, both going up and coming down.

Calibrate a vacuum gage.

Calibrate several thermometers.

Plot a set of correction curves for each pressure gage and vacuum gage, with gage readings as abscissae and standard readings as ordinates.

Plot a set of correction curves for each thermometer with observed temperatures as abscissae and correct temperatures as ordinates.

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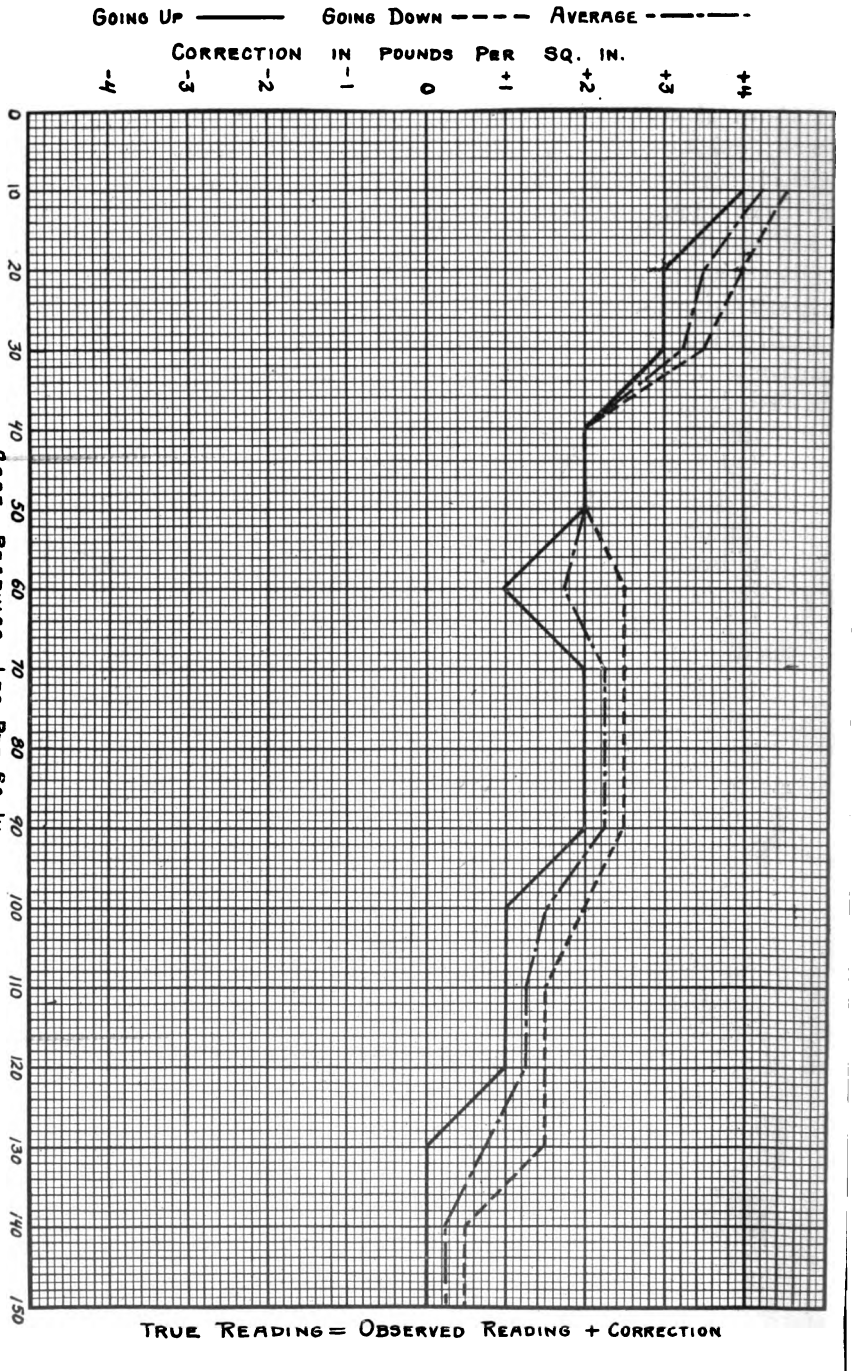

FIG. 2. CALIBRATION CURVE

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Plot a curve for steam above 212° F. and 14.7 lb. absolute pressure, with temperature as ordinates and pressure as abscissae.

In plotting your correction or calibration curves follow the curves as illustrated in the cut on page 26. Plot a separate curve for increasing increments and a separate curve for decreasing increments. Plus corrections are indicated above the zero line and minus corrections are indicated below the zero line. Join all of your points by straight lines from point to point. A mean curve can be drawn in half-way between the curves for increasing increments and decreasing increments.

All curves called for other than calibration curves should be smooth curves drawn as nearly as possible through the points as plotted on your cross-section paper.

Calibration of Gage by Gage Tester

Make of gage..... No. of gage.....
Date of test..... Observers.....

Going Up			Going Down			
Pressure on standard	Pressure on gage	Correction	Pressure on standard	Pressure on gage	Correction	Remarks

Calibration of Vacuum Gage

Make of gage..... No. of gage.....
Date of test..... Barometer.....
Observers..... Temp. of mercury column.....

Going Up			Going Down			
Mercury column	Vacuum on gage	Correction	Mercury column	Vacuum on gage	Correction	Remarks

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Calibration of Thermometers

Kind of thermometers..... No. of thermometer.....
Date of test..... Barometer.....
Observers.....

Pressure on gage	Pressure corrected from tests	Absolute pressure	Corresponding temperature	Thermometer 1		Thermometer 2	
				Observed	Correction	Observed	Correction

Thermometer Immersion Test

Kind of thermometer..... No. of thermometer.....
Date of test..... Observers.....

Correct temperature	Depth of immersion	Corresponding temperature	Correction

Experiment No. 2

INDICATORS

It is often desirable to ascertain the power developed in an engine cylinder and the changes of the working medium during the cycle, whether this medium be steam, combustible gaseous mixtures, air, or ammonia. These can be ascertained by the use of an indicator which traces a diagram on a suitable card. This diagram shows the simultaneous relations between pressure on one given side of the piston and distance passed over by the piston, measured from the ends of its stroke. As the product of pressure and distance passed over is equivalent to power, the area of the figure represents on some known scale the mechanical energy being developed in the cylinder.

The requirements of a perfect indicator are, that its moving parts shall be as light weight as permissible, that these shall be free from friction though the piston must be a tight fit, that the pencil motion

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shall be parallel to the axis of the paper drum and without lost motion, and that all pencil movements shall be proportional to the pressure under the piston.

Fig. 3 shows a section of the Crosby indicator. It consists of a cylinder (A) which partially steam jackets itself; a piston whose upward movement is resisted by a finely tempered spring, works in this cylinder. The top of the piston rod connects to a parallel motion device which is mounted on the casing in such a way that it can be swung about the drum as an axis. The outer end of this parallel motion carries a pencil point which can draw the diagram on a card mounted on the oscillating drum (24). This drum is oscillated by a cord connected to a reducing motion whereby its movement is made proportional to the travel of the piston. Inside the drum is a spring to maintain a proper tension in the cord and to return it to its original position.

The indicator is fitted to the cylinder of an engine by connecting the nut (7) to the top of a three-way cock which has a direct connection with the interior of the cylinder. This three-way cock can connect direct to the cylinder or blow into the atmosphere through a small blow hole. An indicator is a delicate and very expensive instrument and should be handled with great care. Under no circumstances should wrenches be used other than those provided with the instrument. The use of pipe wrenches, gas pliers, and monkey wrenches on any parts shows bad judgment and should be especially avoided.

Indicators of different makes differ in details but the general principles are the same. The special directions for the Crosby indicator given by the manufacturers are as follows:

To remove the piston, spring, etc., unscrew the cap, then lift by the sleeve all the connected parts free of the cylinder. This gives access to these parts for cleaning and oiling.

To detach the spring, unscrew the piston and piston rod from the swivel head, holding the cap (2) from turning. Then with the socket wrench accompanying the instrument, unscrew the piston rod from the piston and lift off the spring. To attach a spring, slip it over the socket wrench and piston rod until the bead rests in the small socket at the end of the rod. Replace the piston and screw it firmly into place, first loosening slightly the lower piston screw (9). After the piston is tightened, this should be set up again lightly to prevent lost motion but not tight enough to prevent the bead from turning.

After the piston is screwed on tight, hold the sleeve and pencil motion in an upright position, slip the piston rod up over the threaded

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portion of the swivel head (11) until the threads on the upper head of the spring engage those on the cap (2). Then screw the spring firmly onto the cap. Now allow the cap to turn and screw the piston rod onto the swivel head, until the top of the rod is nearly flush with the shoulder on the swivel head. The piston, after it has received a light

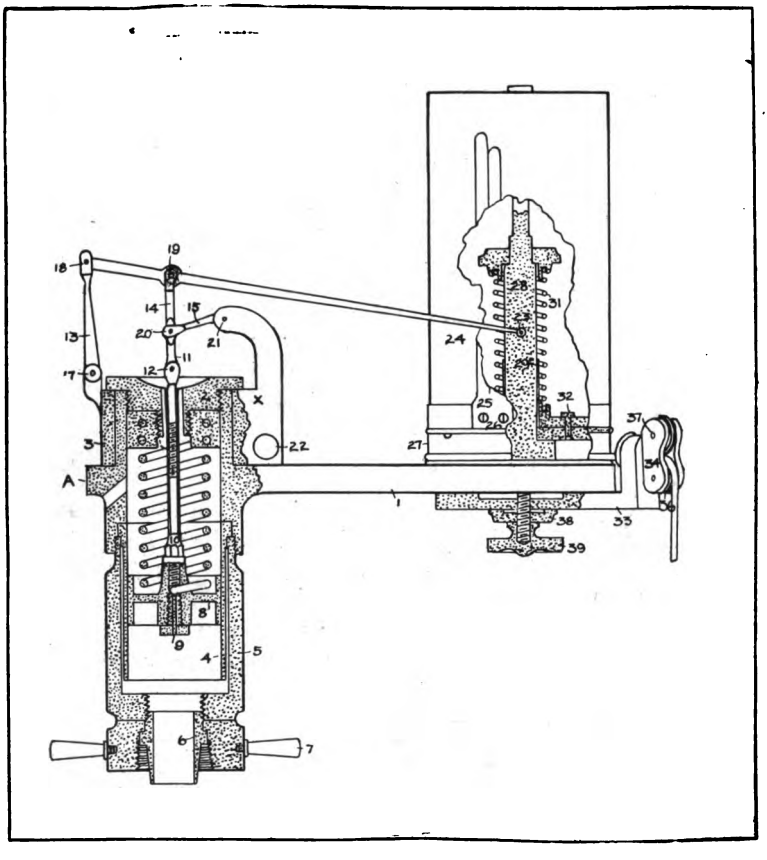

FIG. 3. CROSS SECTION OF CROSBY INDICATOR

coat of heavy cylinder oil, may now be inserted in the cylinder, and the cap screwed into place.

To change the location of the atmospheric line, unscrew the cap and remove the piston and pencil movement from the cylinder. Unscrew the piston rod from the swivel head to raise the atmospheric line and screw it in to lower it. One complete turn will change the position of the pencil about $\frac{1}{8}''$.

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Adjust the pencil point so that it will not tear the paper.

To change the drum tension, remove the drum, lift the knurled nut at the top of the drum spring from its square seat, turn in the direction required and replace it on its seat. Never remove the pins or screws at the joints of the parallel motion but keep them well oiled with the *oil provided* for that purpose.

Other makes of indicators such as the Tabor, the Thompson, the Schaeffer & Budenberg, differ somewhat from the one which has just been described. The student should familiarize himself with the various makes and learn how to change springs and make adjustments in each.

Some new indicators are fitted with springs outside the cylinders. These are very desirable for superheated steam or other high temperature work.

Indicator springs are usually of helical form and when in use, one end is screwed to the upper head of the cylinder and the other to the free moving piston. They are designated by the number of pounds per sq. in. required to move the pencil point one inch vertically on the card. This is known as the "scale" of the spring. In selecting a spring for use in any given case, it is advisable to choose one whose scale is about ⅔ of the maximum pressure to be measured. When working with high speeds, stiffer springs should be used.

Before using an indicator, thoroughly clean and oil all moving parts. Remove the piston and just before test, apply a light coat of heavy cylinder lubricating oil.

In an indicator the two commonest sources of error are the pencil motion and the spring. To test the former, place a card on the drum and draw the atmospheric line. Remove the spring and place the pencil in contact with the paper and raise it to the full height of its travel. Repeat this at several points on the card, holding the drum firmly in each position. Remove the card and test the perpendicularity of the lines with a triangle and straight edge.

Calibration of Indicator Springs

Indicator springs are often tested under hydraulic pressure and sometimes by the pressure exerted by a rod on the under side of the piston, the lower end of the rod resting on suitable scales. As the indicator is subjected to the heat of the steam when in use, probably the most satisfactory method of calibration is to test the spring by known steam pressures. However, it is generally found difficult to maintain a constant pressure and to determine accurately this

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pressure. Steam gages are sometimes used for this purpose, but they may themselves be subject to errors and are sometimes sluggish in action especially for small variations of pressure. A method of calibration similar to that used for testing gages has been found very satisfactory.

The apparatus consists of a steam drum with a pressure regulating valve which maintains the pressure constant at any point desired.

Fig. 4 shows the general arrangement of the apparatus. A piston of known area is exposed on one side to the pressure in the drum. The other side carries a platform on which weights can be added to

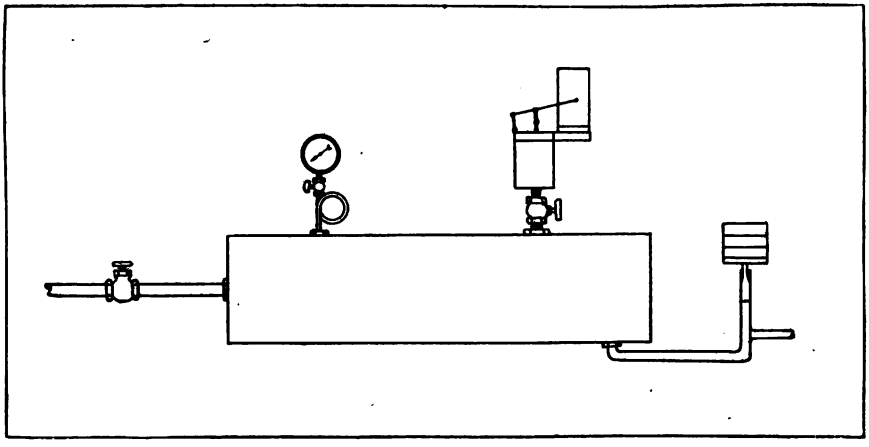

FIG. 4. INDICATOR TESTER

balance the pressure on the under side. The piston is free to move between stops and as it rises it opens a port of increasing depth through which the steam escapes until the pressure is just sufficient to sustain the weights. The entering steam is controlled by a valve at the other end of the cylinder. The area of the piston is usually made $\frac{1}{5}$ sq. in. and the weight of piston and platform exactly 1 pound. Then the weights belonging to the Crosby gage tester can be used and the pressure on the indicator accurately determined.

To test an indicator spring, attach the indicator containing the spring, to the testing outfit. Allow steam to enter and warm up the drum. Drain off the condensation. Adjust the steam inlet valve until the platform with a given known weight, floats freely. Open and close the indicator cock several times to see that the cylinder is free from water. With the cock so that the cylinder is open to atmos-

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phere, draw the atmospheric line. Open the cock. Twirl the platform and make a record on the indicator card by revolving the drum by hand. In order to determine whether there is lost motion in any of the parts, after making a record, gently press the pencil arm up or down as the pressures increase or decrease. Then draw a second line for this pressure. If there is no lost motion these lines will coincide. Before putting the paper on the indicator drum, draw upon it two parallel vertical lines about ¼″ apart (a) and (b), Fig. 5.

When testing with increasing pressure, draw lines toward the right from the left vertical. When decreasing pressures are being used,

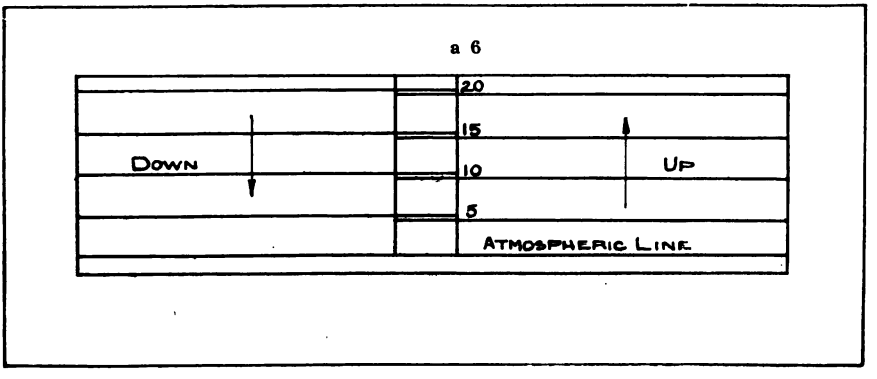

FIG. 5. DIAGRAM SHOWING CARD FROM INDICATOR SPRING

draw lines toward the left beginning with the right vertical. For springs under 30 lb. make a record every 5 lb. change in pressure. For springs over 30 lb. make 10 lb. changes.

The diagram drawn by an indicator when attached to an engine, furnishes a means for determining the action of the valve, for analyzing the action of the steam in the cylinder, and for determining the power developed. It is assumed that the student knows the meaning of the terms used in connection with indicator cards, designating the events of the stroke as admission, cut-off, release, and compression.

The percentage of stroke at the different events is the distance of the piston from the end of the stroke from which it is receding, expressed as a percentage of the total length of the stroke.

The location of the events of the stroke on a card especially at high speed, requires considerable skill. In locating, for instance, the point of cut-off, the best method is to follow up the curve with the eye until the point is reached at which the reverse curve begins.

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This point may be taken as the point of cut-off. Similarly for release, follow down the expansion curve until the point is reached at which the reverse curve leading to the back pressure line begins. This is the point of release.

Steam Accounted for by Indicator Diagrams at Points Near Cut-off and Release*

The steam accounted for, expressed in pounds per i.h.p. per hour, may readily be found by using the formula

$$\frac{13{,}750}{\text{m.e.p.}}\left[(C+E)\,W_c-(H+E)\,W_h\right]$$

in which

m.e.p.=mean effective pressure.

C=proportion of direct stroke completed at points on expansion line near cut-off or release.

E=proportion of clearance.

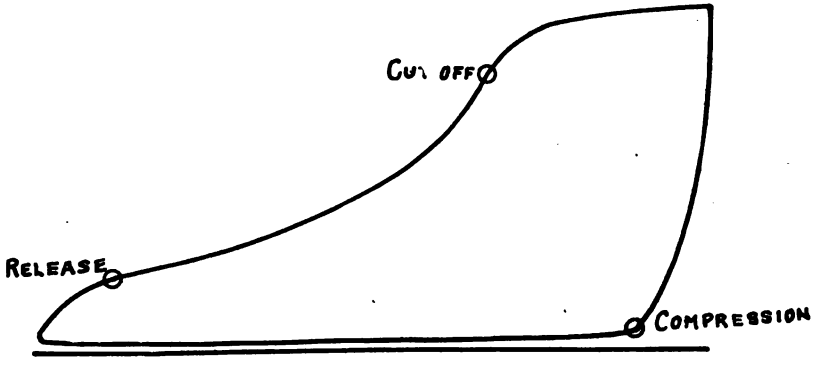

FIG. 6. POINTS WHERE "STEAM ACCOUNTED FOR BY INDICATOR IS COMPUTED'

H=proportion of return stroke uncompleted at point on compression line just after exhaust closure.

W_c=weight of 1 cu. ft. steam at pressure shown at cut-off or release point.

W_h=weight of 1 cu. ft. steam at pressure shown at compression point.

The points near cut-off, release, and compression referred to are indicated in Fig. 6.

In multiple expansion engines the mean effective pressure to be used in the above formula is the aggregate m.e.p. referred to the cylinder under consideration. In a compound engine the aggregate m.e.p. for the h.p. cylinder is the sum of the actual m.e.p. of the h.p. cylinder and that of the l.p. cylinder multiplied by the cylinder ratio. Likewise the aggregate m.e.p. for the l.p. cylinder is the sum of the actual m.e.p. of the l.p. cylinder and the m.e.p. of the h.p. cylinder divided by the cylinder ratio. (See Appendix No. 34.)*

* Taken from *A. S. M. E. Test Code*, 1915.

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The relation between the weight of steam shown by the indicator at any point in the expansion line and the weight of the mixture of steam and water in the cylinder may be represented graphically by plotting on the diagram a saturated steam curve showing the total consumption per stroke (including steam retained at compression) and comparing the abscissae of this curve with the abscissae of the expansion line, both measured from the line of no clearance.

:–Off and Ratio of Expansion

To find the percentage of cut-off, or what may best be termed the "commercial cut-off," the following rule should be observed:

Through the point of maximum pressure during admission draw a line parallel to the atmospheric line. Through a point on the expansion line where the cut-off is complete draw a hyperbolic curve. The intersection of these two lines is the point of commercial cut-off, and the proportion of cut-off is found by dividing the length measured on the diagram up to this point by the total length.

To find the ratio of expansion divide the volume corresponding to the piston displacement, including clearance, by the volume of the steam at the commercial cut-off, including clearance.

In a multiple expansion engine the ratio of expansion is found by dividing the volume of the l.p. cylinder, including clearance, by the volume of the h.p. cylinder at the commercial cut-off, including clearance.

Always draw the atmospheric pressure line when taking a card.

The maximum motion of the indicator drum is usually less than ır inches. Consequently it cannot be connected directly to the ıss head of an engine, but must be connected to some apparatus ; in amplitude but corresponding exactly in all its positions to the ;ition of the cross head. Such apparatus is called a reducing mo-n. It is not proposed to describe the various types of reducing tions. These will be studied as they are met with in further tests.

Phosphor bronze wire is sometimes used instead of cord to con-:t the reducing motion to the indicator as it is less liable to stretch.

Do not drop indicator parts on the floor. The slightest injury ›ils the accuracy and usefulness of the instrument.

Always warm up the indicator before taking cards.

Directions for Experiment

Take at least two types of indicators apart, examine them carefully l note the construction of the various parts.

Assemble without the spring, after oiling the piston and place a 'd in the drum. Test the perpendicularity of the pencil motion.

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Assemble with the spring. Correct any lost motion. Test t spring as directed taking at least two cards. Tabulate results as following forms.

Plot a calibration curve for the indicator spring according to structions as outlined in Experiment No. 1.

Attach the indicator to an engine and take a number of ca at different loads. Note the reducing motion used, also measure t speed of the engine. When only one indicator is used for both en of the cylinder, be very careful to see that it is only connected to o end at a time. When finished with an indicator, clean it carefu and put it away.

Find area of cards and m.e.p. by means of a planimeter. C culate i.h.p. Mark events of the stroke and tabulate data as Form 2.

Form 1. TEST OF INDICATOR

Type of indicator..... Scale of spring.....
Date of test..... Observer.....

PRESSURE GOING UP				PRESSURE GOING DOWN			
Pressure from standard	Ordinate from card	Corresponding pressure from scale of spring	Correction + or —	Pressure from standard	Ordinate from card	Corresponding pressure from scale of spring	Correct + or

Form 2 TEST OF INDICATOR

Type of indicator..... Scale of spring.....
Name of engine..... Diameter of cylinder.....
Length of stroke..... Date of test.....
Observers.....

No. of card	m.e.p.	r.p.m.	i.h.p.	PRESSURES						PER CENT OF STRO			
				Admission	Cut-off	Release	Compression	Steam line pressure	Back	Admission	Cut-off	Release	Com-

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NSTRUCTIONS FOR HANDLING CROSBY CONTINUOUS INDICATORS

This drum is designed to use a roll of paper 2 inches wide and 12 t long upon which the operation of the indicator traces a series of grams which will continue until the roll is exhausted unless inter- ted by the operator. The roll of paper is located within an open- in the shell of the drum, thence the paper passes around the out- e of the drum and inward to the central cylinder to which it is ached. The central cylinder is concentric with the drum, and er the paper has been wound upon it, may be withdrawn through top and the paper easily detached. Upon the top of the drum l cooperating with the central cylinder is a knurled head loosely ached to the drum spindle, which controls the distance between diagrams so that by adjustment they will vary in number from o 100 per foot of paper.

1. To Adjust the Drum:

To take any desired number of diagrams on a roll of paper, first n the central knurled head to the right, clockwise, to its stop to re- se the pawl; then remove the central knurled head from the top of drum, held to the drum spindle by a spring latch, readily released a slight upward pull. Then having loosened the screw in the eve bearing the character "1 Ft.," turn this sleeve to the desired sition. The figures on the collar below the sleeve indicate the mber of diagrams, each 4 inches long, which may be taken on each t of the roll of paper. Fix the sleeve in place by setting the screw mly back to its seat; and replace the knurled head in the center the drum, carefully fitting it to its squared seat, turning it slightly the left and throwing in the two pawls so they will engage the ner and outer ratchets on the collar of the central cylinder. After e diagrams are taken, the roll of paper may be removed by dis- gaging both pawls and withdrawing this central paper cylinder. The taking of diagrams can be suspended at will by disengaging e inner pawl from the ratcheted collar of the central paper cylinder turning the central knurled head to the right, or may be resumed turning the knurled head in the reverse direction to the left until e inner pawl re-engages with the ratcheted collar.

2. To Apply the Roll of Paper:

Pass the free end of the roll of paper through the wide opening in e side of the drum; release the central paper cylinder, by throwing e outer pawl and withdrawing the inner pawl from its ratcheted llar by turning the central knurled head to the right, and draw the

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cylinder upward far enough to permit the paper to slip under the attached clip; then push it down to its place with the paper under the clip, with the metallic surface inward toward the paper cylinder; afterwards turn the paper cylinder to the left, counter-clockwise, until the paper is drawn tight with the metallic surface inward. Carry the roll of paper to the left entirely around the outside of the drum, with the metallic surface outward, passing it underneath the fixed brass marking-point; unscrew the spindle in front of the middle of the broad opening of the drum by means of its enlarged top; slip the roll of paper into the opening; pass the spindle through the small hole in the center of the paper roll and secure it in place by screwing the spindle to its seat in the base of the drum.

Experiment No. 3

CALORIMETERS

The steam coming from a boiler, unless superheated, usually carries a small percentage of moisture. This is due to some extent to bubbles of steam rising to the surface of the boiling water which, on breaking at the surface, carry with them minute particles of water. As this bubbling depends on the rate of driving, boilers produce wetter steam at heavy than at light loads.

It is important to know the amount of this moisture in any given weight of steam as the economy of both boilers and of steam engines is affected by this moisture content. Instruments that are used to measure the quality of the steam, are known as calorimeters.

Two types of calorimeters are in common use, the throttling and the separating. Throttling calorimeters give accurate results where the moisture is less than 3 per cent of the total steam. Separating calorimeters may be used with moisture of 3 per cent or over.

The separating calorimeter is an instrument which removes all the water from the steam by some process of mechanical separation. Water is many times heavier than steam. Hence, if the sample of steam, when moving at a considerable velocity, can be made to change its direction of flow abruptly, the water will be deposited by the action of inertia.

The instrument consists of two cylindrical vessels, one placed inside of the other. The steam space between the outer and inner vessels acts as a steam jacket. The interior vessel is provided with

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a gage glass (a) Fig. 7 and a scale graduated to read in $\frac{1}{100}$ lb. The sample of the steam whose quality is to be determined enters the pipe (b) strikes the cup (c) and its direction is completely reversed. By this action the water is thrown to the outer edges of the cup (c), due to its inertia, and drops into the chamber (d). As this chamber is not disturbed by any flow of steam, the moisture collects quietly

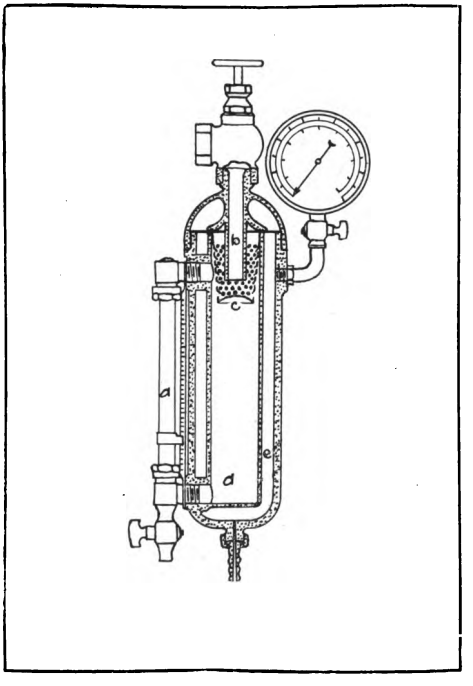

FIG. 7. SEPARATING CALORIMETER

and is shown on the gage glass (a). The steam leaves the chamber (d) at the top and passes around throughout the jacket space (e).

Radiation from the inner chamber is almost entirely eliminated in this way. The steam then escapes by the nozzle shown at the bottom and is led to a vessel where it is condensed and measured. Let the weight of the moisture collected in a given time as shown on the gage glass be represented by W_1 and the weight of dry steam condensed in the condenser be represented by W_2. Then the percentage of moisture to the whole quantity is

$$y = \frac{W_1}{W_1 + W_2}$$

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The percentage of dry steam is

$$X = 1 - y = \left(1 - \frac{W_1}{W_1 + W_2}\right) = \frac{W_2}{W_1 + W_2}$$

This calorimeter is usually supplied with a small pressure gage which is provided with two scales. The inside scale reads gage pressure in pounds per sq. in. while the outside scale indicates pounds of dry steam discharged through the nozzle of the calorimeter in 10 minutes.

The method of taking a sample of steam is of great importance. For instance, a sample from the outer edge of a pipe would probably show too high a moisture content owing to the condensation loss around the circumference of the pipe. A sample taken from the center of the pipe, would show very dry steam. Hence a sampling pipe is necessary. It is customary with high pressure steam to plug one end of the sampling pipe and drill it full of holes about one-eighth in. diameter for such a distance that it will reach about two-thirds across the pipe in which it will be used. A very fair average sample for the whole pipe will thus be obtained. This pipe must be heavily lagged to prevent radiation loss.

The separating calorimeter is seldom used where the percentage of moisture is less than 3 per cent, for the small radiation losses cause a proportionally large error in the observations. A throttling calorimeter can measure these small percentages very accurately. The throttling calorimeter is based on the principle that if the pressure of the steam is changed without doing work, the difference in the total heat of the steam at the higher pressure and the total heat of dry saturated steam at lower pressure, is expended first in evaporating any moisture in the steam, and second, if there is any heat remaining, in superheating the whole volume of the steam at the lower pressure.

The calorimeter as usually constructed consists of a cylindrical vessel (a), Fig. 8, which should be heavily lagged to prevent radiation loss, in which is inserted a thermometer well (b). Steam is drawn through a sampling tube (l) from the steam line (h) in which the pressure is shown by an accurate pressure gage (k). This steam is expanded without doing work through the nozzle (c) into the vessel (a). It escapes to the atmosphere through the passage (g). The pressure in the calorimeter is shown on a mercury column (f) and can be increased to any value desired by closing the valve (g). All pressures should be reduced to absolute pressures. Let r_1 = latent heat due to the pressure in the main steam pipe, x_1 = unknown quality, q_1

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= heat of the liquid at that pressure, λ_2 = total heat of 1 pound of dry steam at the calorimeter pressure, T_2 = the steam temperature corresponding to this pressure as given in the steam tables, T_3 = temperature observed on the thermometer placed in the calorimeter and C_p = the specific heat of superheated steam at the pressure in the calorimeter = .48. When steam passes through a nozzle from one pressure to another without doing work, the heat contents before and after the nozzle must be equal.

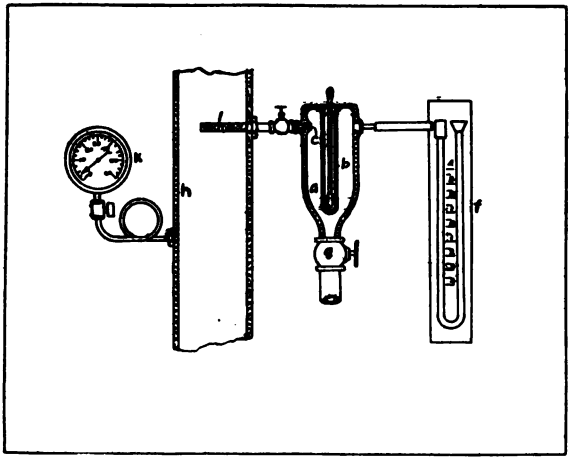

FIG. 8. THROTTLING CALORIMETER

Hence

$$x_1 r_1 + q_1 = \lambda_2 + C_p (T_3 - T_2)$$

$$\therefore x_1 = \frac{\lambda_2 - q_1 + C_p (T_3 - T_2)}{r_1}$$

The Mollier diagram can be used to advantage in many computations. For instance, suppose a throttling calorimeter is used to determine the quality of the steam. The absolute pressure in the calorimeter can be determined by adding the calorimeter back pressure to the barometer height and converting this pressure into pounds per sq. in. absolute. On the diagram follow along the line of this constant pressure until the observed temperature is reached. The total heat in the steam in the calorimeter can now be read from its proper scale. But according to the theory of this calorimeter, the pressure has changed without doing work and the total heat contents of a pound of the steam must be the same in the calorimeter as in the steam line. Hence the total heat per pound of steam in the steam

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line has been found. Since this change of pressure has taken place without change of heat, the quality of the steam at the initial condition is determined by the point where the constant heat line cuts the line of observed constant absolute pressure on the steam line.

Let it be assumed that the heat available from an adiabatic expansion in a Rankine cycle must be found. Find the total heat in the steam at the beginning of this expansion either from the calorimeter readings or from the known quality and pressure. On a Mollier chart such an expansion follows a line of constant entropy. Hence the heat at the end of an expansion in a Rankine cycle can be found by following a constant entropy line from the point representing the initial state of the steam to its intersection with the line representing the absolute back pressure. The difference between these two heat values represents the heat available from expansion in a Rankine cycle.*

Care should be taken in connecting the mercury manometer to a throttling calorimeter to see that there is a loop in the rubber connection so that any condensation will drain into the calorimeter and not into the manometer. Water in manometer columns can be removed by soaking it up with strips of blotting paper.

Either the separating or throttling calorimeter alone does not give accurate results on steam pressures below about 30 pounds. It has been found, however, that very accurate results may be obtained by placing a throttling calorimeter on the exhaust of a separating calorimeter. Such an instrument is fully described in a paper by Stott and Pigott on "A 15,000 K. W. Steam-Engine Turbine, Unit," Vol. 32, *Transactions A. S. M. E.*, to which the student is referred should he have occasion to make low pressure tests.

Professor Thomas has patented an electric calorimeter which gives very accurate results. When it is advisable to use this instrument a description of its principles and operation may be obtained from one of the laboratory instructors.

Test of a Separating Calorimeter

In using this instrument allow steam to blow through until it is thoroughly heated and allow sufficient water to gather in the separating chamber to reach the zero mark on the scale. Fill the condensing vessel with cold water and note carefully the initial level on the glass at the beginning of the test and the weight of water in the condensing vessel. The test should now be run until the separating chamber is

*A Mollier diagram for use with the throttling calorimeter will be found on page 44.

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nearly filled when the readings should again be taken of both weights. The connection from the steam pipe to the calorimeter should be well covered with some pipe covering to avoid radiation losses.

Make a series of tests and record on form following.

Test of Throttling Calorimeter

Connect up the calorimeter. Cover connection and calorimeter thoroughly with pipe covering. See that thermometer well is filled with heavy cylinder oil. Insert the thermometer. Attach a calibrated steam gage to the steam line and a U shaped mercury column to the calorimeter chamber. Warm up the calorimeter and when the temperature on the thermometer becomes constant, start to take readings. Take readings 5 minutes apart for about a half hour and record on accompanying form.

In your report describe the calorimeters, and the location of the calorimeters relative to the engine. Describe fully the steps taken to make the test.

Steam Separator Test

This test is made to show the application of calorimeters to determine the efficiency of a steam separator. Calorimeters should be placed both before the separator and between the separator and the engine. A comparison of the quality of the steam as shown by the readings of these calorimeters will show the efficiency of the separator. To check this efficiency, condense all the steam passing through the engine. The water separated in the separator will be indicated on the gage glass. Hold this water at a constant level, blowing all surplus water out into a tub containing cold water, and weigh it. The ratio of the weight of this water to the weight of condensed steam represents the percentage of water removed by the separator and should equal the difference between the two calorimeter readings.

In your report describe the principles and construction of the steam separator used. Report on the form for the separator test.

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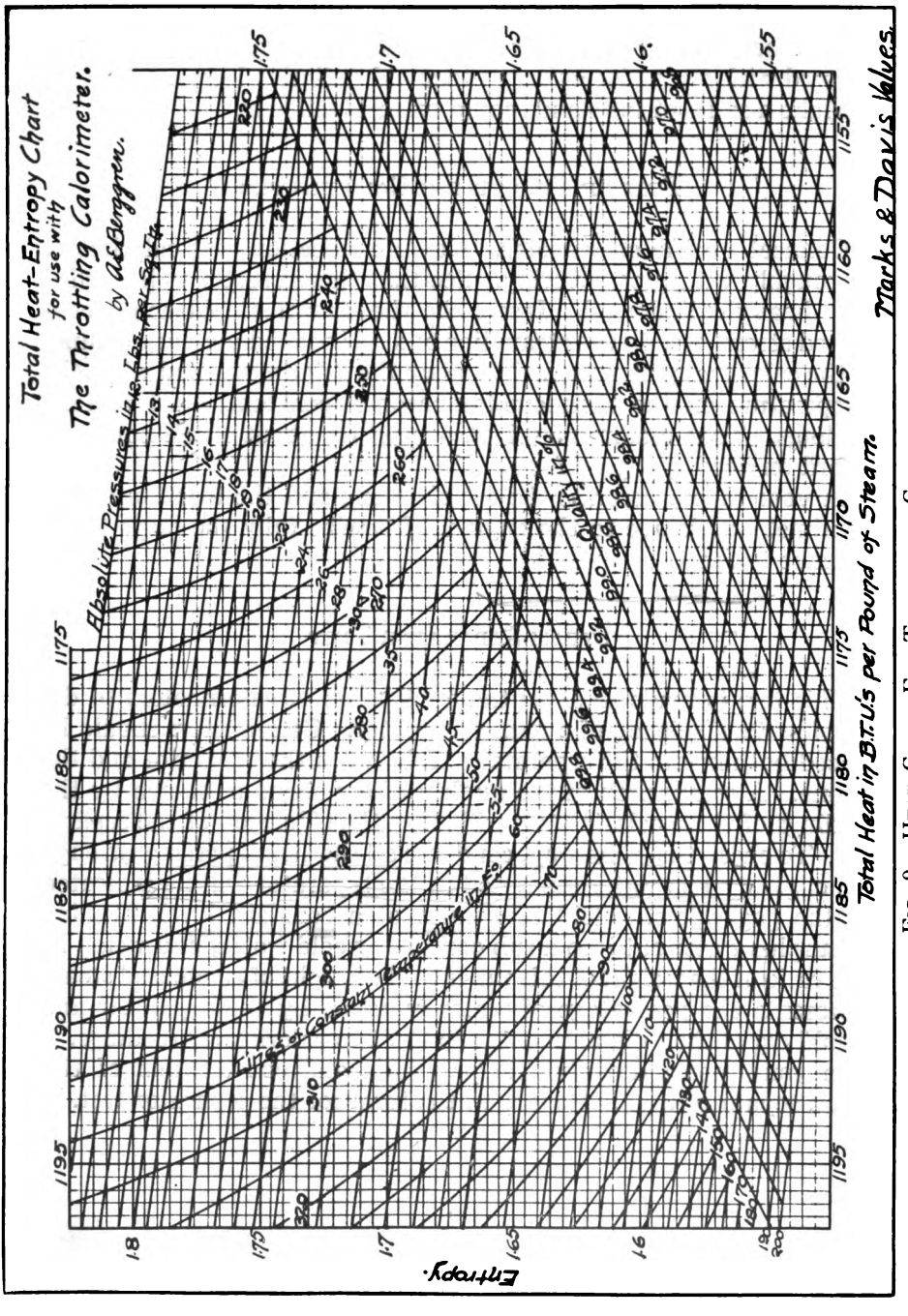
Total Heat-Entropy Chart
for use with
The Throttling Calorimeter.
by A.E. Burgess.
Absolute Pressures in the Lbs. per Sq. In.
Lines of Constant Temperature in Deg. F.
Entropy.
Total Heat in B.T.U.'s per Pound of Steam.
Marks & Davis Values.

FIG. 9. HEAT CHART FOR THROTTLING CALORIMETER

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Test of Separating Calorimeter

Calorimeter No..... Date.....
Barometer..... Observers.....

Time	Duration of run	Gage pressure	Absolute pressure	Pounds of Water		Moisture per cent	Quality
				Calorimeter	Condensed steam		

Test of Throttling Calorimeter

Calorimeter No..... Date.....
Barometer..... Observers.....

Time	Steam pressure in steam pipe	Absolute pressure in steam main	Back pressure in calorimeter	Absolute pressure in calorimeter	Corresponding temp. of saturated steam	Observ'd temp. in calorimeter	Superheat in calorimeter	Moisture in steam	Quality

Test of Steam Separator

Made at.....On.....Engine.....
Type of calorimeter above separator.....below separator.....
Observers..... Date of Test.....

Time	Steam pressure	Calorimeter No. 1			Calorimeter No. 2			Weights		Per cent separated by weight	Per cent separated by calorimeters	Efficiency of separator by calorimeters
		Back pressure	Temperature	Quality	Back pressure	Temperature	Quality	Condensed steam	Water separated by calorimeter			

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Experiment No. 4

PLANIMETERS

A planimeter is an instrument used for finding the area of any plane figure. The type in common use was invented by Amsler and is known as the polar planimeter.

It consists of an arm EF, Fig. 10, carrying a record wheel D and a tracing point F and pivoted at E to a second arm EP. When in use the point P is fixed and held by a small weight, and the tracing point F is moved by hand around the outline of the figure whose area is to

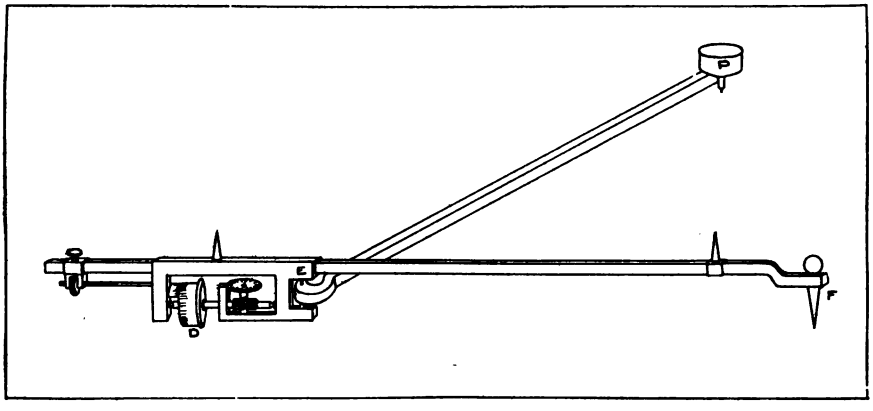

Fig. 10. Amsler Planimeter

be measured, in a clockwise direction. The area of the figure can be proved to be equal to the product of the circumferential rotation of the record wheel D and the length of the pivot arm EF. When the length of the arm EF is fixed the record wheel is divided off in graduations which are proportional to the area. Thus the area can be read direct from the wheel.

The theory of the planimeter and the proof of the preceding statements are too lengthy to include in this text, but will be found in Carpenter's *Experimental Engineering* or Moyer's *Power Plant Testing.*

If the planimeter be moved so that the plane of its record wheel at all times passes through the fixed point P, no record is made as the wheel is travelling in the direction of its axis. If a complete revolution is made under these conditions, the circle drawn by the tracing point is known as the "zero circle." In planimetering large areas

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where the tracing point moves completely around the fixed point it is necessary to know the area of the zero circle since the reading indicated on the planimeter is not the area traversed but is the difference in area between the area of the zero circle and the area traversed. If the tracing point be moved completely around the fixed point in a clockwise direction the wheel will give a positive or a negative reading. If the area traversed is greater than the area of the zero circle the reading will be positive. If the area is less than the area of the zero circle the reading will be negative.

In planimetering areas approximately equal to the area of the zero circle it is sometimes difficult to determine whether your reading is positive or negative. In cases of this kind divide the areas in two parts and planimeter them separately in which case your reading is bound to be negative.

The zero circle may be found as follows,—by placing the point P in the center, measure the area of a circle of known area and greater than the area of the zero circle. Let the area of such circle be A_1 and the record on the registering wheel be R_1 in proper units. Let the radius of the zero circle be r. Then

$$\pi r^2 + R_1 = A_1$$
$$\pi r^2 = A_1 - R_1$$
$$= \text{area of zero circle}$$

It has been stated that the area of a figure equals the product of the length of the pivot arm and the circumferential rotation of the record wheel. If the length of the pivot arm be adjustable and be made equal to the length of the figure, then the rotation of the record wheel will be proportional to the height of the figure.

The arm with the tracing point carries on its upper side two long points which are so set as to remain always the same distance apart as the arm EF. Hence if these two upper points are set equal to the length of a figure, the distance EF is also equal to the length of the figure. Several planimeters are made in which the pivot arm can be adjusted in this way. The record wheel in this case is graduated to read the mean effective pressure of the diagram directly for some given spring. On the Crosby planimeters used in the laboratory, this given spring is 40 lb. When a different spring has been used in taking the diagram, multiply the readings of the record wheel by the proportion of this spring to the fixed spring of the planimeter.

When it is desired to measure areas in sq. in. with this planimeter, set the mark on the frame carrying the recording wheel opposite the line marked "10 sq. in." on the tracing arm.

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The plane of the record wheel must be perpendicular to the tracing arm, otherwise an error will result. Any change in the diameter of the record wheel due to wear or dirt, will require a corresponding change in the tracing arm. Also any irregularity in the edge of this wheel will make the relative amounts of slipping and rolling motion uncertain and consequently impair its accuracy. It is, therefore, necessary to handle the instrument with greatest care. All moving parts are held by pivot bearings which should have no lost motion. The record wheel should spin around easily in its pivots but should not be loose.

In working with the planimeter use a smooth level surface and cover it with heavy drawing paper upon which the record wheel is to move. Fasten the diagram to be measured on this paper by means of thumb tacks. Keep the rim of the record wheel clean and free from rust and before using wipe clean with a soft rag or handkerchief. Avoid touching this wheel afterwards with the bare fingers.

To check the instrument for error, draw carefully two rectangles, each 3 in. long, one 1 in. high and the other 2 in. high. Find the areas of these by going over them at least three times each. Calculate the average error of the planimeter reading. Another method is to take a small German-silver rule which has a small needle-point near one end and small holes at exact distances from this point of 1 in., 2 in., and 3 in. on the other side. Stick this rule on a drawing board and mark the starting point. Place the tracing point of the planimeter in one of the holes, note the reading of the record wheel, and revolve the rule through one complete revolution about the needle-point as center. Compare the area read from the record wheel with the known areas of circles of 1 in., 2 in., or 3 in. radius. Compare the observed error with the error found by the method of rectangles.

In measuring a diagram, select the fixed point so that the instrument in its initial position will leave the tracing arm perpendicular to the pole arm. Mark a starting point and trace the outline of the area to be measured in the direction of the hands of a watch, slowly and carefully returning to the starting point. Note the reading of the record wheel at the instant of starting and stopping. It is generally more accurate to note the initial reading of the record wheel than to try to set it at zero before tracing around the diagram.

If the problem is to find the area in certain units from a diagram drawn to scale, such as a map, cross section of a structure, or a similar figure, the tracing arm can be set to read directly the units re-

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quired. The method of calculating the length of this arm can be found in Art. 131 of Johnson & Smith's *Theory and Practice of Surveying.*

Directions for Experiment

Find the area of the zero circle for some known length of pivot arm other than that stamped on the instrument. Find the average error of the instrument by one or both of the above methods. Find the mean effective pressure of the cards taken by the indicator. It is advisable to go over each card at least three times to insure accuracy.

Experiment No. 5

TEST OF LUBRICANTS

Oil is one of the commonest materials used in engineering and yet one which usually receives least attention. Even in small plants, the oil bills run into large sums each year. The criterion of the cost of a suitable oil for a given purpose, is the length of time a certain quantity lasts in service as compared with the cost of power in overcoming friction and the maintenance charges on parts in friction contact. In manufacturing plants the friction loss is seldom less than 5 per cent and sometimes as high as 30 per cent. Hence the selection of suitable oils is of very great importance.

In testing oils the following determinations should be made:

(1) The composition and the detection of adulteration and acids.

(2) The measurement of density.

(3) The determination of viscosity.

(4) The flash temperature, the burning temperature, and the chill point.

(5) The determination of its condition as to grit, foreign matter, etc.

Adulteration can be detected only by chemical analysis. For some purposes, such as steam turbine work, animal and vegetable oils cannot be used on account of their tendencies to decompose and to cause foaming. A simple test for these adulterations is to shake the oil with chlorine gas. Animal oils turn brown, and vegetable oils white.

Oils containing acids should be condemned and never allowed to be put in use. The heat developed in a bearing under average conditions will be sufficient to start corrosive actions often due to electro-

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chemical effects. A simple test for acids is to drop a piece of blue litmus paper into the oil. If the paper turns red, there is acid present.

To determine the density of oil, pour enough in a large test tube or jar to float a hydrometer. The density can then be read off directly on a scale, which may read either true specific gravity, or an arbitrary scale of specific gravity known as the Baumé which is of importance as it is used to a considerable extent in oil engine work.

The Baumé readings may be converted into true specific gravity by means of a table, as in Kent's *Mechanical Engineer's Pocket Book*. The temperature of the oil at the time of the test should be noted. Check the hydrometer in a jar of pure distilled water.

The viscosity of an oil is closely related but not proportional to its density. It is also closely related to and in many cases it is inversely proportional to its lubricating properties. The relation of the viscosities at ordinary temperatures is not the same as for higher temperatures, and tests for viscosity should be made with the temperature equal to that to which the oil will rise in the bearings.

The less the viscosity of the oil consistent with the pressure to which it is subjected the less is the friction. The viscosity test is very important in determining the lubricating qualities of an oil.

Viscosity may be expressed as "specific" viscosity or "absolute" viscosity. As a basis for the measurement of specific viscosity the following materials have been employed by different investigators using different viscosimeters—water, rape oil, castor oil, phenol, glycerine solutions, sugar solutions, petroleum products, and fish oils. The coefficient of viscosity of a fluid may be defined as "the tangential force on unit of area of either of two horizontal planes at unit distance apart, one of which is fixed while the other moves with unit velocity, the space between them being filled with the viscous material. When all the units are expressed in the c. g. s. system the result thus obtained is the absolute viscosity."

For further information of the subject consider the thesis of H. F. Zabel, Wisconsin, '14, on *Viscosimeters and Viscosity*, extracts from which are included in this experiment.

CLASSIFICATION OF VISCOSIMETERS

Class 1. *Short Capillary.* In meters of this type, the liquid to be tested is forced either by gravity or by pressure through the capillary and the viscosity is determined in terms of the time required for a given volume to pass through the meter, as compared with the time required for the same volume of a standard liquid to pass through the meter.

Class 2. *Orifice.* This type employs an orifice in place of the short capillary of the previous type. The Carpenter meter belongs to this class.

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Class 3. *Dropping a solid body through a tube filled with the liquid,* the solid body being usually a sphere or a plunger. Meters employing this principle determine the viscosity in terms of the time required for the body to drop a certain distance through the liquid, as compared with the time required for the same body to drop through a standard liquid. To this class of meters belongs the Perkins meter, which employs a plunger and vertical tube, and the Flowers meter, which employs a small steel sphere and a slanting tube.

Class 4. *Oscillating Disk or Cylinder.* These meters determine the viscosity in terms of the damping which the oscillating disk or cylinder experiences when placed in the liquid as compared with the damping when placed in the standard liquid. The Doolittle meter is an example of this class.

Class 5. *Rotating Disk or Cylinder.* This type determines the viscosity in terms of the speed of rotation of the disk or cylinder in the liquid under test as compared with the speed of rotation in the standard, the driving torque remaining constant. The Stormer meter is an example of this class.

Since viscosity is determined with technical instruments in a variety of ways, the viscosity as expressed in terms of one apparatus will be fundamentally and numerically different from that of another kind of apparatus. The following examples will serve to show the general lack of uniformity in making viscosity measurements.

The Engler degree of viscosity, or specific viscosity, is expressed as the time in seconds required for 200 cc. of a fluid at a certain temperature to flow from the orifice of the apparatus divided by the time in seconds required for 200 cc. of water at 20 deg. C. to flow out.

To obtain the viscosity in Redwood degrees the time of flow of the fluid to be tested is multiplied by 100 and divided by 535, the number of seconds it requires 50 cc. of refined rape oil at 60 deg. F. to flow from the orifice. If it is desired to make the correction for specific gravity, the result should be multiplied by the specific gravity of the fluid under examination at the temperature of the experiment and divided by 0.915, the specific gravity of rape oil at 60 deg. F. The final result thus represents the viscosity of the fluid at the temperature of the experiment as compared to rape oil at 60 deg. F.

In the Doolittle apparatus torsion in a wire causes a cylinder to rotate vertically in the liquid under examination. The number of degrees difference between the first and second swings in the same direction is noted. The results are expressed as the number of grams of sugar contained in 100 cc. of sugar syrup at 60 deg. F., its viscosity being taken at 80 deg. F. If for example, 17 deg. F. represents a viscosity of 65.6, this means that if 65.6 grams of granulated sugar were dissolved in water at 60 deg. F. and made up to 100 cc. and

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heated to 80 deg. F. its viscosity would be the same as that under consideration.

The Stormer viscosimeter is operated by a falling weight which revolves a vertical drum in the liquid to be tested. It appears that with this apparatus viscosity can be expressed in two ways. In the 1911 *J. Ind. and Chem. Eng.*, this statement was made: "The index of viscosity may be considered as the force required to produce a given shear in a given time; if we adopt a minute as the unit of time and the shear produced by 100 revolutions of the stirrer as unit shear the viscosity will be indicated by the number of grams required to revolve the stirrer 100 times in one minute." A friction allowance of about 5 grams must be made.

In a later article published in the 1912 *J. Soc. Chem. Ind.* the directions were given as follows: "Take the time for 100 revolutions in water as unity, then the relative viscosity of another fluid will be the time required for 100 revolutions divided by the time for 100 revolutions in water. If the liquid is found too viscous for comparison, first determine the viscosity of an intermediate liquid, increase the weight, and use the intermediate liquid as the standard. After this calculate back to water as unity." This apparatus has three different sized driving weights. Viscosity can thus be expressed as grams or seconds when using the Stormer viscosimeter.

The four Saybolt viscosimeters A, B, C, and the Universal are supposed to be used for certain oils and definite temperatures. According to Gill's *Oil Analysis*, A is the standard for testing Atlantic red, paraffin, and other distilled oils at 70 deg. F. B is designed for testing black oils at 0 deg., 15 deg., 25 deg., and 30 deg., cold test, and other reduced oils up to, but not including, summer cold test oil at 70 deg. F. Apparatus C is used for testing reduced, summer, cylinder, filtered cylinder, XXX valve, 26.5 $^{\circ}B_e'$., and other heavy oils at 212 deg. F. The standard Universal viscosimeter is used for testing cylinder, valve, and similar oils at 210 deg. F., reduced black oils at 130 deg. F., spindle, paraffin, red, and other distilled oils at 100 deg. F.

The operation of the Saybolt A, and probably B, is as follows: Liquid is poured into the apparatus until the top of the overflow cup is reached. The viscosity at 70 deg. F. is the number of seconds required for the first appearance of the liquid surface in the peep hole.

Apparatus C is filled with the fluid to be tested until the overflow is reached; the temperature being at 212 deg. F., the cork is drawn and the number of seconds required by 60 cc. of the fluid to flow out is the viscosity.

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The time required for 60 cc. of liquid to flow from the Universal apparatus is the desired viscosity.

Specific viscosity as expressed by the Scott viscosimeter is the number of seconds required for 50 cc. of the material under examination to flow out divided by the water figure at 60 deg. F.

There seems to be some question as to how viscosity is obtained with the Tagliabue viscosimeter. Wm. Davis in *Friction and Lubrication* gives this information: "To obtain the viscosity at 70 deg. F. the nozzle labeled 70 is screwed on to the orifice, 70 cc. of fluid is put into the container, and the time in seconds required for 50 cc. of this material to flow out is multiplied by two." For 212 deg. F. the nozzle labeled 212 is used.

The Engler viscosimeter, as a scientific and accurate instrument, probably surpasses all other viscosimeters of the technical types.

The following temperatures for commercial liquids have been accepted as standard for viscosity determinations by the American Society for Testing Materials.

1.	Machine, engine and dynamo oils	70 deg. and 120 deg. F.
2.	Cylinder, valve, and crank case oils	18 deg., 212 deg., and 300 deg. F.
3.	Linseed and other paint oils	70 deg. and 120 deg. F.
4.	Molasses, glycerine, and sugar solutions	70 deg. F.
5.	Varnish, Japan, etc	70 deg. F.
6.	Waxes and greases	180 deg. and 212 deg. F.
7.	Glue and gelatine solutions	90 deg. F.

Glue and gelatine solutions are made up by first soaking 50 grams of glue or gelatine in about 100 cc. of cold water until softened. After this the material is liquified by means of a water bath, and is finally made up exactly to 200 cc. at 90 deg. with more warm water.

In the experiment in the laboratory a Carpenter orifice viscosimeter will be used. This consists of a vessel surrounded by a water-jacket in which the water can be heated by an auxiliary lamp and maintained at any desired temperature. The vessel is fitted with a hook gage at the top and also a thermometer and has a plug in the lower end. Water is taken as the standard of flow. The viscosimeter and the measuring jar should be thoroughly cleaned before use.

First make several runs with water as follows: Fill the vessel with water at 68° F. temperature until the hook gage just shows level. Open the orifice at the bottom and note the time with a stop watch of the flow of 100 cc. into a graduated flask.

To test the oil remove the water from the graduated flask and vessel. Clean and dry thoroughly. Fill the vessel with oil and note

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the time of flow of 100 cc. Heat the jacket water and make seven runs between the temperature of the room and boiling temperature. The average of the temperature at the start and finish of each run is assumed as the temperature of the run.

From these readings plot a curve for oil on one sheet, with temperatures as abscissae and time of flow as ordinates. Calculate the viscosity of the oil with reference to water for several temperatures from values taken from this cruve. Plot a curve with temperatures as abscissae and viscosity as ordinates.

The viscosity of the oil is usually expressed with reference to water. Thus let t_o = time required for 100 cc. of oil to pass through a given orifice at a given temperature and let t_w be the time required for a similar amount of water at 68° F.

$$\text{Then viscosity } V = \frac{t_o}{t_w}.$$

By making a series of tests on several samples of oils a series of curves can be plotted and that oil which shows the proper amount of flow at a given temperature can be selected for the purpose in view. It must be noted whether or not this oil is too dense at a slightly lower temperature.

To determine the chill point, pour about ½ in. of oil into a test tube and place a low reading thermometer in it.

Pack the test tube in a brass cylinder with a freezing mixture of ice and salt. The drain in the bottom of this cylinder should be left open. Allow the oil to freeze or congeal. The chill point may be determined by either or both of the following methods:

(1) Remove the tube and invert it at an angle of 60° and note the temperature at which the oil starts to run down the sides of the tube.

(2) When the oil has congealed, withdraw the thermometer with as much of the frozen oil as possible. At the instant when the oil commences to form a globule on the end of the bulb, read the temperature.

The observed temperature in either case is the chill point.

FLASH POINT

For a thorough discussion of the flash points of oils consult *Technical Paper 49* by the Department of the Interior, Bureau of Mines.

In the various methods used for determining the flash point of an oil the temperature at which its vapor flashes is not a definite factor

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but is dependent on a number of physical and chemical conditions not under the control of the operator. The flash point is not an indication of the value of an oil for any particular purpose. It is an indication only of the temperature at which the oil gives off vapors in such volume that they form an inflammable mixture with the air. If exposed to an electric spark or a flame, the mixture will ignite and the flame extend throughout the mixture; that is, the mixture of vapor and air is explosive. The flash point is of importance mainly in connection with fire hazards.

The fire hazard of lubricating oils is of importance when the lubricants are used for rapidly running machinery, as in spinning mills or wood mills, or are used in factories containing combustibles and in compressors for air, ammonia, or other gases.

Flash point testers are embodied in the following classes: (1) Open-cup testers, (2) semiclosed testers, (3) closed testers, (4) open testers with saturated vapors, (5) vapor-pressure testers, and (6) distilling testers.

In this experiment the flash point of a lubricating oil will be determined by means of an open tester immersed in a sand bath.

The distance of the test flame above the oil surface is important. The test flame should be at a definite and constant distance above the surface of the oil, as the distance affects the temperature of the bath, the vapors, and the oil. The farther the test flame is from the surface of the oil, the later the flash and the higher the flash point determined. The test flame should not be brought too near to the oil nor should the exposure be too long, for local heating will result and will cause an error in the reading.

To determine the "flash point," fill a small brass cup about two-thirds full of oil and immerse it in a sand bath. In it suspend a 600° F. thermometer which does not touch either the bottom or the sides of the cup. Light a gas burner under the sand bath and by heating it raise the temperature of the oil. When the temperature of the oil has risen to about 350° F., test the vapors given off by means of a lighted taper, which is passed directly over the top of the cup and not into it. Note the temperature at which the vapor first ignites with a flash. This is the "flash point" and indicates the temperature at which the oil commences to break up and to give off vapors.

Continue to heat the oil until gases are given off in sufficient quantity to burn for several seconds. This temperature is the "burning point" and fixes the temperature at which there is danger of fire should the oil be exposed to any flame.

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Grit and foreign matter may be removed by filtering the oil through oil filters, many types of which are now on the market.

The loss by evaporation at any temperature can be determined by heating the oil at this temperature for about 12 hours. This test is important when it is thought that oils are adulterated with kerosene or other light oils.

Testing of Steam Turbine Oils

The increasing use of steam turbines and other high speed machinery in which oil is used continuously under exacting conditions makes necessary a study of the properties of these oils.

Such a lubricant must be a pure mineral oil free from acids, vegetable and animal oils, paraffin, or water. Clearness and freedom from turbidity are the main essentials.

When water is present in oil, there is a tendency for such oil to foam and later on to form an emulsion which greatly reduces the lubricating value of the oil.

Acids may be detected as noted before. An oil containing animal or vegetable oils may work well for a time but as a rule soon breaks down. The simplest test for these adulterants is to shake a portion of the oil in a clean bottle with a strong solution of borax. A milky white emulsion will form if these oils are present. After standing in a cool place for some time the clear mineral oil will come to the top and the remainder of the borax solution will go to the bottom while the emulsion will form between them.

Oils containing paraffin or other waxy substances will give trouble on account of the clogging of the bearings when same are closely adjusted, with the result that heating may occur. Filters and oil screens are also clogged up.

Investigations have shown that color is no indication of the value of an oil. Nor is filtering necessary since as good results have been obtained with dark oils under exacting conditions as with amber-colored oils. The point of importance appears to be that the oils have been filtered or else chemically treated in such a manner that the waxy substances or the so-called amorphous waxes have been completely removed and on heating a sample to 450° F. only a slight darkening of color results.

Test a sample of turbine oil by heating it for five minutes at a temperature of 450° F. It should show not more than a slight darkening of color if the amorphous waxes are not present.

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It is known that the elimination of the waxes causes a decided increase in the ease with which the oil separates from hot water when thoroughly shaken with it. This condition can be taken advantage of by prescribing that when one ounce of the oil is placed in a four-ounce sample bottle with two ounces of boiling water, the bottle corked and shaken hard for one minute and let stand, the oil must separate from the water within a specified time depending upon the nature of the oil and that there must be no appearance of waxy substances at the line of demarcation between the oil and the water.

An important test on gas engine oils is to filter them through white filter paper and see if there is any carbon deposit. The presence of carbon may be due to too high a temperature of distillation of the oil, to the distillation of the oil being carried too far, or to imperfect filtration of oils that have been heated too high. Such an oil will frequently break up in the cylinder and deposit carbon, rendering it entirely unsuitable for gas engine use. Only oils from a paraffin base and not a tar base should be used on gas engine cylinders.

Vegetable oils are used for lubrication purposes, only in exceptional cases, though such oils as linseed oil, olive oil, etc., are largely used for commercial and manufacturing purposes.

Animal oils rapidly decompose in use and become rancid. They are frequently used in mixing cylinder oils to be used with low pressure and without superheat. Lard oil is used as a lubricant in fine tool work in machine shops and on the dies of pipe cutting machines.

Solid oils are mineral compounds with a high chill point.

Greases are various compounds of oils and fats thickened with sufficient soap to form a more or less solid substance at ordinary temperatures. Engine greases are usually thickened with a soap made from tallow or lard oil and caustic soda and often contain neatsfoot oil, beeswax, etc.

Graphite is a solid inorganic substance used as a lubricant. However, it is generally mixed with oil before being forced into bearings. Defloculated graphite is a product of the electric furnace in which the particles are reduced to a very fine state of subdivision so that when mixed with oil these particles will remain in suspension and act as part of the oil itself. This mixture is known to the trade as "oildag" and is an excellent lubricant.

Directions for Test

Two samples of oil will be tested in the laboratory. Determine whether acid is present in either sample and also test for animal and vegetable matter with a borax solution.

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Measure the density of each sample.

Determine the viscosity of one sample and plot the curves noted above.

Test for the chill point, the flash point, and the burning point.

Report tests on forms following:

OIL TESTING

Logs of Viscosity Test

Kind of oil	Made by
Color	Specific gravity
Acid	Chill point
Flashing point	Burning point
Date	Observers

WATER TEST

Test No.									
Temperature									
Time required for flow of 100 c. c									

OIL TEST

Test No.	Temperature at start	Temperature at end	Average temperature	Time required for 100 c. c	Viscosity water =1.0

EXPERIMENT NO. 6

SLIDE VALVE SETTING

The economical use of steam in a steam engine depends to a great extent upon its proper distribution in the cylinder. This requires careful setting of the valves and adjustment of the valve gear. These adjustments may be made in two ways, from measurements taken directly from the valve or by the use of an indicator. Both methods are used in practice. The valves are usually first set by measurement and afterwards checked by taking indicator cards from the engine when in operation. An indicator must generally be used when setting valves on high speed engines or where valves are inaccessible for

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measurement. Slide valves and other slow speed engine valves are usually set by measurement.

Setting the Slide Valve

The Richards engine will be used for this experiment in the laboratory. Remove the cover from the steam chest and take out the valve. With calipers and scale, measure the dimensions of valve, ports, throw of the eccentric and length of connecting rod.

Find the dead center of the engine in the following manner: Place a mark on the crank end of the crosshead. Turn the engine over in the direction of rotation until the crosshead is within ¼ in. or so of its extreme crank end position. Draw a mark on the guides to correspond with the mark on the crosshead in this position. Take a trammel about equal in length to the distance from the center of the shaft to the floor, and place one end of this on some fixed spot on the floor in front of the flywheel, with the other end scribe a line on the face of the flywheel. Now pull the engine over center in the direction of rotation until the mark on the crosshead corresponds on the return stroke to the fixed mark on the guide. Scribe a second line on the flywheel. Bisect the distance between these two lines and place a line on the flywheel at this point. When the flywheel is turned in the direction of rotation until the trammel point just coincides with this line the engine is on the crank end dead center.

Repeat the operation for the head end.

In setting valves on engines of any type whatever, it is absolutely essential that the engine be turned only in the direction in which it will rotate, for only in that way will the lost motion in the valve mechanism be the same as in actual operation.

Replace the valve and adjust the valve on the valve stem so that for one complete revolution of the engine, the valve has symmetrical travel. By symmetrical travel is meant the position of the valve on the stem where for one revolution of the engine the over travel of the valve on the head end port equals the over travel on the crank end port. Next, place the engine on head end dead center, loosen the eccentric and shift the eccentric until the valve has the desired lead. Turn the engine over to crank end dead center and see if the crank end lead corresponds to the head end lead. Because the valve has been adjusted for symmetrical travel the crank end lead should be practically the same as the head end lead. An error, known as error due to the angularity of the connecting rod, prevents the two leads from being exactly the same on the first trial. Your instructor

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will explain in detail this error. Adjust the valve for equal leads by shortening or lengthening the valve stem.

In tightening the nuts that hold the valve on its stem, always allow enough clearance so that the valve is free and not jambed, about .010 in. is enough.

It is sometimes desirable to set the valve for equal cut-off, that is, so that cut-off occurs at the same percentage of both strokes. With the valve still in the setting for equal leads, find the percentage of stroke at which cut-off takes place on the outward stroke by observing relative marks on crosshead and guide. Then turn the engine over to the same percentage of the return stroke. If the valve is now cutting off, the setting is correct. If the port is still open, shorten the valve stem, and if the port is covered, lengthen the valve stem, by an amount equal to one-half the difference between the two positions. Record the effect of this setting on each lead.

Equality of leads generally gives more quiet running. Set again for equal leads of $\frac{3}{16}$ in. and close the steam chest. Place and adjust an indicator on the pipe connections for that purpose; apply a brake load and take a card from each end. Inspect the cards for the events of the stroke and make any necessary changes to improve them, checking each change by new cards. When the best possible card is obtained, every member of the class will take a set for his own report. Take the r.p.m. of the engine when this card is taken. Now remove the steam chest cover and note the changed dimensions of lead and cut-off.

Set the eccentric so that the engine will run in the reverse direction.

Determine from the set of cards included with the report, where the events, admission, cut off, release, and compression take place and tabulate them as percentage of stroke in the following form. Also measure the pressures at these events from the atmospheric line. Determine the m.e.p. and calculate the i.h.p. for each end.

The report should contain a brief description of the engine, including cylinder dimensions, a dimensioned sketch of valve and valve seat, and detailed description of the successive steps of the valve setting, with the recorded dimensions of lead and cut-off. The cards obtained from the final setting should be discussed with reference to events of stroke and criticized as to faults and possible improvement. Explain the setting for reversed rotation of the engine. Include a description and dimensioned sketch of the reducing motion, and discuss its accuracy. Determine steam and exhaust lap. Mechanical

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engineering students draw to scale a Bilgram valve diagram for this engine. How would you make cut-off earlier?

The Richards engine has an 8 in. x 12 in. cylinder with a $1\frac{3}{8}$ in. piston rod.

SLIDE VALVE SETTING, INDICATOR TEST

Name of engine..... Diameter of cylinder.....
Length of stroke..... r. p. m.....
Diameter of piston rod.....
Date of test..... Observers.....

Card No.	Time	Per cent of Stroke				Lead	Pressures				m.e.p.	r.p.m.	i.h.p.
		Admission	Cut-off	Release	Compression		Admission	Cut-off	Release	Compression			

EXPERIMENT NO. 7

TEST OF A SIMPLE THROTTLING ENGINE

Engines are often sold with a guarantee as to the steam consumption at a given load under conditions specified in the contract. It is often desirable to verify this guarantee by an actual test. Tests are also frequently made to find out whether the valves, pistons, etc., are tight or leaking badly. Before making a test all apparatus to be used, such as thermometers, gages, indicator springs, etc., should be carefully calibrated.

In this experiment tests will be made to determine the thermal and mechanical efficiencies and commercial economy of a simple engine with a throttling governor. The steam consumption of at least four loads will be determined. It must be kept in mind that in testing a heat engine, the object sought is to determine the amount of work developed by the engine from a given amount of heat supplied. In the case of a steam engine, the heat supplied can be found from the weight and the initial and final conditions of the steam used. These conditions are determined by the pressure and quality of the steam at the throttle of the engine and the pressure of the exhaust. Its weight is determined by weighing the condensed steam when a

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surface condenser is used or weighing the feed water to the boiler in any other case. The work developed may be determined from indicator cards, from a form of brake or dynamometer, or from the output of a direct connected electric generator. The heat passing out of the exhaust may be determined from measurements on the condenser or by special means.

Commercial guarantees are usually made on the basis of steam consumption at some rated load, in pounds per indicated horsepower-hour, per brake horsepower-hour, or per kilowatt-hour, with steam arriving at the throttle at a given pressure and quality and with a given pressure in the exhaust.

Connect a calorimeter to the steam main for determining the quality of the entering steam. Attach a gage to read the pressure of the steam supplied to the engine.

Attach indicators to the cylinder and adjust the reducing motion. Sketch and describe this motion in your report. Connect a continuous revolution counter to some portion of the moving parts to record the revolutions or use a hand speed counter during the test.

Place a Prony brake on the brake wheel and determine its constants. The constants to be found are—length of brake arm, and the unbalanced dead weight of the brake arm acting at the fulcrum of this arm.

There are several methods of determining this unbalanced dead weight. One simple method is to oil the brake wheel thoroughly, pulling the brake up and down until it moves freely and loosely. Then rap both sides with hammers, striking moderately sharp blows around the top of the brake band. At the same time the unbalanced weight on the scales should be noted.

Still another method is to clamp the brake, not too tight to prevent its turning, and pull it through a small arc about its horizontal position, by means of a small balance. Note the reading of the balance pulling up and pulling down and calculate the dead weight.

Read the temperature of the engine room and of the calorimeter.

Before attempting to start any engine always fill the oil cups and the cylinder lubricator. Make a special study of the construction and operation of this lubricator. In your report of this test, show a section of the lubricator and describe its principles. Whenever a condenser is to be used in a test, take particular pains to see that the cooling water is turned on before any steam is turned into the engine. Neglect to do this is gross carelessness as hot steam damages the dry condenser tubes.

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Open the cylinder drain cocks and warm up the cylinder by slightly cracking the throttle valve. It is absolutely essential in every case to have the cylinder drains wide open on starting up any engine; otherwise the cold cylinder naturally condenses the steam, fills with water and a water hammer is liable to be set up or the piston may force one of the heads out. This will not only seriously damage the engine but may cause bodily injury also. Always keep your own safety well in mind when working around machinery.

Start the engine and bring it slowly up to speed. Close the cylinder drain cocks. After the engine has run at speed for a few minutes, take a number of indicator cards with no load on the brake. This represents the friction load of the engine. Turn water on the brake wheel to keep it cool.

Run four 20-minute tests on the engine at approximately ¼, ½, ¾, and full load, taking all readings and indicator cards every five minutes. Report your data on the following forms. In your report comment on the effect of the throttling governor as shown by the indicator cards.

In plotting your curves plot as many curves on one sheet as is practicable. Do not crowd too much, but do not use a single sheet for each curve unless it is necessary.

Plot curves with i.h.p. as abscissae and total steam, pounds of steam per i.h.p. hour, mechanical efficiency and thermal efficiency as ordinates.

Also plot curves with br. h.p. as abscissae and pounds of steam per br. h.p. hour as ordinates.

In your report state whether the friction horse power remains constant at all loads.

The engine used on this test will be the Nagle vertical engine whose cylinder is 7 in. x 7 in. with 1⅛ in. piston rod. The maximum r.p.m. of the engine is 240, which can be varied by altering the spring tension on the throttling governor. The engine is geared to a shaft carrying the brake by means of a Renold Silent Chain. The student's attention is called to the operation of this transmission device. The ratio of engine speed to brake shaft speed is 2 to 1. The brake arm is 3 ft. 0 in. long.

In the final report the items "the per cent stroke at cut-off and release and the absolute pressures at the various events" need only be found for one card at each load. Omit the heat balance on this test.

Keep a copy of the general data and results of this test on file in your room in order that you can use these results to compare with

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the results of similar tests as you perform tests on different engines in the laboratory.

Keep copies of the general data and results of all tests that you conduct in the laboratory in order to make comparisons as called for as you progress in your laboratory work.

TEST OF.....ENGINE

GENERAL LOG

Diameter of cylinder..... Brake arm.....
Length of stroke..... Dead load on brake.....
Diameter of piston rod..... Barometer.....
Area of piston head end..... Date of test.....
Area of piston crank end..... Observers.....

Time	Continuous counter	r.p.m.	PRESSURES			TEMPERATURES					WEIGHTS		Cubic feet of cooling water	m.e.p.	
			Steam line	Calorimeter	Condenser	Engine room	Calorimeter	Condensed steam	Injection	Discharge	Condensed steam	Brake load		Head	Crank

In the appendix at the back of the *Laboratory Manual* will be found a complete table of data and results of steam engine test code as compiled by the American Society of Mechanical Engineers in the code of 1915. The items in the following table of data and results have been taken from this code and the numbers of the items correspond to the numbers in the test code with some slight modifications to fit conditions in the laboratory.

DATA AND RESULTS

(1) Test of.....engine located at.....
(6) Diameter of cylinder.....in.....
(7) Stroke of piston.....ft.....
(11) Date.....
(12) Duration.....hr.
(13) Pressure in steam pipe near throttle, by gage.....lb. per sq. in.
(13a) " " " " " " absolute.....lb. per sq. in.
(14) Barometric pressure.....in. of mercury
(20) Temperature of steam near throttle.....deg.
(21) Temperature of steam in exhaust pipe near engine.....deg.
(c) Temperature of air in engine room.....deg.
(22) Percentage of moisture in steam near throttle or number of degrees of superheating.....per cent or deg.
(24) Total condensed steam from surface condenser (corrected for condenser leakage).....lb.
(25) Total dry steam consumed (Item 23 or 24 less moisture in steam).....lb
(31) Commercial cut-off in per cent of stroke.....per cent.....
(33) Back pressure at lowest point above or below atmosphere.....lb. per sq. in.....

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(34) Mean effective pressure { H. E. ..... lb. per sq. in. .....
C. E. ..... lb. per sq. in. .....
(37) Indicator Cards
(a) Pressure at selected point near cut-off ..... lb. per sq. in. .....
(b) Pressure at selected point near release ..... lb. per sq. in. .....
(c) Pressure at point on compression curve shortly after exhaust closure ..... lb. per sq. in. .....
(d) Proportion of direct stroke completed at selected point near cut-off .....
(e) Proportion of direct stroke completed at selected point near release .....
(f) Proportion of return stroke uncompleted at selected point on compression line .....
(40) Indicated h.p. developed { H. E. ..... i.h.p.
C. E. ..... i.h.p.
Total ..... i.h.p.
41) Brake h.p. ..... br. h.p.

EFFICIENCY RESULTS

(49) Thermal efficiency of engine referred to i.h.p. .....
(51) Efficiency of Rankine cycle between temperatures of Items 20 and 21 .....
(52) Rankine cycle ratio referred to i.h.p. (Item 49 ÷ Item 51) .....

EXPERIMENT NO. 8

TEST OF A HIGH SPEED ENGINE

If the student has not already performed the test of the simple throttling engine, he is advised to read the notes on how this test should be conducted before reading the following notes on the High Speed Engine.

As in the case of the simple throttling engine, these tests are made to determine the thermal and mechanical efficiencies and commercial economy of the engine under several loads. The effect of the flywheel governor and the high speed will also be noted both on the indicator cards and on the steam consumption.

This engine automatically varies all points on the cards according to the load. It is equipped with a balanced double-ported slide valve and automatic flywheel governor.

In your report describe the principle and action of the governor.

Run four 20-minute tests at approximately ½, ¾, full load, and 1¼ loads. Plot the same curves as asked for in Experiment 7.

In conducting this experiment follow the general directions as outlined in Experiment 7, and report data on forms as given for the same experiment.

The Weston engine is normally rated at 75 i.h.p. at 250 r.p.m. Its cylinder is 10 in. by 13 in. with a 1¾ in. piston rod. The brake arm is 5 ft. long.

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EXPERIMENT NO. 9

IDEAL HIGH SPEED ENGINE

The object of this experiment is the same as for Experiments 7 and 8, the only difference being that instead of using a Prony brake for the measurement of power this engine is direct connected to a 15 kilowatt 110 volt direct current compound wound generator. Use a water rheostat for loading the generator as outlined in the experiment on the steam turbine. The engine is equipped with an automatic flywheel governor, similar to the Weston high speed engine but has a balanced piston valve. The sizes of the engine are as follows: cylinder diameter $7\frac{3}{32}''$ x 10″ stroke: piston rod $1\frac{7}{16}''$.

Run four 20-minute tests at approximately ½, ¾, full load, and 1¼ loads. Plot the same curves as asked for in Experiment 7.

In conducting this experiment follow the general directions as outlined in Experiment 7, and report data on forms as given for the same experiment.

Include the electrical readings of the generator as outlined in the Steam Turbine Test and compare your results with the results of other engine tests you have conducted in the laboratory.

EXPERIMENT NO. 10

STUDY OF STEPHENSON LINK MOTION

The Stephenson Link Motion, while being far from the best and most economical valve gear, adapts itself peculiarly to the locomotive and is extensively used on that class of engine.

Its chief advantages are that it is the best reversible gear, that it permits a change of steam distribution under running conditions by the simple movement of a lever in the engineer's cab, that it has few parts and bearings and that these parts can be made of strong construction.

The Stephenson Link Motion has the disadvantage that it has to use a slide valve which has many faults and also that the gear takes up practically all the room under the boiler and between the wheels which might be utilized for some other purpose.

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For further information regarding this Link Motion, the student is referred to a text on valve gears or to McShanes', *The Locomotive Up-to-Date.*

The laboratory is provided with a model of the Stephenson Link Motion on which the valve travel, size of ports, angle of eccentrics and length of reach rods can be varied. One of the eccentric discs is graduated in degrees. The cylinder is graduated in percentage of stroke and the piston carries a small pointer over this scale. By watching the valve, it is possible to determine the percentage of stroke at which each event occurs. The arc carrying the reversing lever has seven positions from full gear forward to full gear backward, marked: full gear forward, No. 6, No. 3, No. 0; No. 3, No. 6, and full gear backward.

The experiment consists of a study of the Stephenson Link Motion from this model. First measure and sketch the valve and valve seats. Also measure the valve travel. Find the dead centers of the crank.

With the reversing lever set in the position of full gear forward, set the throw of the eccentric to get the required valve travel.

Adjust the valve on its stem to get symmetrical travel over the ports. The valve travel should be such that the port opens wide at exhaust. Repeat this setting on the other eccentric with the reverse lever in the position of full gear backward, adjusting the backward eccentric rod to give symmetrical valve travel.

Turn the backward eccentric on the shaft to give a lead of ..... in. at full gear. With reverse lever at full gear forward position, repeat this operation on the forward eccentric.

Throw the reverse lever to full gear backward and check the lead, correcting half the error on the eccentric and half on the eccentric rod. Check the full gear forward leads again in the same way.

Study the effect of setting the reversing lever at the following positions: full gear, No. 6, No. 3, No. 0 forward; No. 3, No. 6, and full gear backward. At each position of the reversing lever note the following events on each end of the cylinder: lead, admission, cut-off, release, and compression.

In the final report discuss the Stephenson Link Motion as applied to locomotives and show a diagrammatic sketch of it.

Show on a sketch the dimensions of valve and valve seat.

Describe how the valve was set.

Draw freehand sketches of head and crank end diagrams both on one card, with the events approximately as found in the experiment, assuming any scale of steam pressure. Discuss the Stephenson Link Motion and its characteristics as shown by these sketches.

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Experiment No. 11

CORLISS VALVE SETTING

By referring to the tests of the slide valve engine, it will be noticed that the cut-off took place at about ¾ stroke. Hence the steam was not expanded to any great extent. On the high speed engine, the point of cut-off was altered to suit the load. But all other points on the diagram were changed at the same time. The clearance volumes were also large.

In speaking of steam engines, the ratio of expansion is the ratio of the volume of the steam in the cylinder at the end of the stroke to that at cut-off. Hence ratio of expansion is equal to

$$\frac{\text{Volume swept through by piston in complete stroke plus clearance volume}}{\text{Volume swept by piston up to cut-off plus clearance volume}}$$

If a valve gear be designed with small clearances and with cut-off taking place early in the stroke, it is evident that a greater range of expansion and more economical use of the steam will be possible. There are several types of such valve gears in use in America. Among them are the Corliss, the Brown, the McIntosh and Seymour, the Nordberg, the Ball and Wood, the Meyer valve gear, etc. Three of these types are in the laboratory, the Corliss, the Nordberg, and the Meyer gear on the air compressor.

The object of this experiment is to study the Corliss valve gear and the method of setting these valves.

The essential features of a Corliss engine are as follows: First, its four semirotary valves, two steam and two exhaust, the latter placed at the bottom of the cylinder to drain out the condensation, and all the valves located in such a manner as to reduce clearance volumes to a minimum.

Second, the employment of a wrist plate obtaining its motion from an eccentric on the main shaft and operating the several valves through radial arms in such a manner as to obtain rapid opening and closing of the valves, and to give full port opening during the periods in which the valves should be opened. Sometimes separate wrist plates are provided for steam and exhaust valves.

Third, a means of releasing the steam valves from the driving mechanism at the proper point in the stroke and closing the valves quickly by means of vacuum dashpots.

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Fourth, a governor driven from the main shaft and so arranged as to be entirely independent of the valve gear, its only purpose being to maintain the point at which cut-off shall occur according to the load on the engine.

The valves may be adjusted by shortening or lengthening the radial arms connecting them to the wrist plate.

Wire drawing at admission and cut-off is avoided to some extent by the quick opening and closing of the valves. Hence the card has corners more nearly square than with a slide valve, which condition tends to improve efficiency.

The Corliss gear provides almost every feature conducive to high economy that is lacking in the slide valve.

Corliss valves are set first by hand and checked over afterwards by means of an indicator. Fig. 11 shows the diagrammatic arrangement of the Corliss valve gear.

To set the valves of a Corliss engine, proceed as follows: Remove the steam bonnets from the ends of the valve chests on the opposite side to the wrist plate and gear. The builders usually show the working edges of the valves and ports by radial lines cut with a sharp chisel on the ends of the valves and valve chests. Both steam and exhaust valves indicate lap when the lines on the valves are nearer the wrist plate than the lines on the valve chest.

Place the wrist plate in its central position, i. e., place it so that the center of the reach rod pin and the center of the wrist plate stud are in a vertical line as shown by the plumb bob. It will be noticed that this point has been marked by the manufacturers by a line on the rear of the wrist plate hub which coincides with a similar line on the wrist plate stud. It will also be noticed that the wrist plate stud had two other lines on it, to right and to left of this central position. These lines denote the extreme positions of the throw of the eccentric when moving symmetrical about the central position.

Unhook the eccentric and set the wrist plate central for adjusting the valve connections, i. e., so that the line on the wrist plate coincides with the central line on the wrist plate stud. Then adjust the length of the connections from the valves to the wrist plate until the steam and exhaust valves have the lap desired. This lap setting can be determined readily by the use of a pair of dividers.

Next find the dead center positions of the crank by using a trammel on the flywheel. For method of determining head and crank end dead centers, refer to experiment number 6 on slide valve setting where this is fully explained. Adjust the length of the eccentric rod

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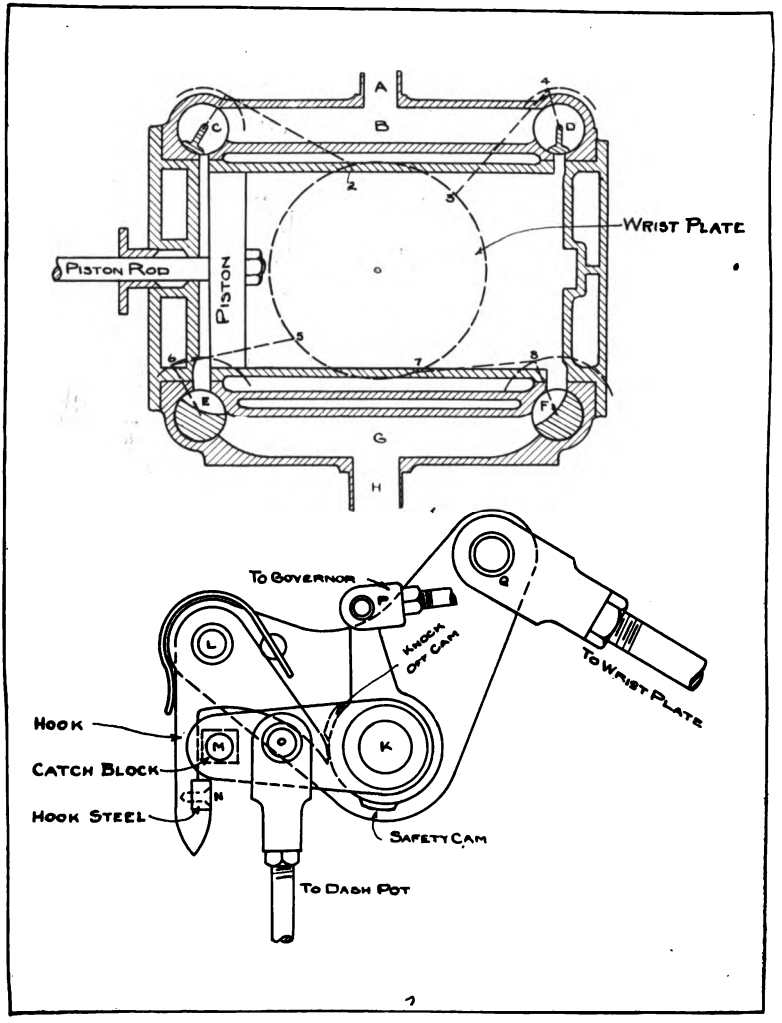

FIG. 11. CORLISS VALVES

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for symmetrical travel of the wrist plate. Set the engine on head end dead center and loosen up the eccentric on the shaft. Hook up the eccentric to the wrist plate and revolve the eccentric ahead until the steam valve on the head end has the desired lead. Clamp the eccentric to the shaft and pull the engine around in the direction of rotation and ascertain whether lead is equal at the other end. If not, adjust the length of the radial arm operating the steam valve for this end, until the required lead is obtained.

Almost every manufacturer has a slightly different setting for his Corliss valves. The following table is supplied by the Allis-Chalmers Co.

Allis-Chalmers Mfg. Co.—A. C. Corliss Engine Valve Settings. Double Ported Steam and Exhaust Valves—Long Range Steam Cut-off.

Diam. Cyls.	Lap of St. Valves Dashpot down	Lead of St. Valves	Lap of Exh. Valves Wrist Plate Central
10	3/16″	1/32″	1/32″
12	3/16″	1/32″	1/32″
14	3/16″	1/32″	1/32″
16	3/16″	1/32″	1/16″
18	1/4 ″	1/32″	1/16″
20	1/4 ″	1/32″	1/16″
22	9/32″	1/32″	1/16″
24	9/32″	1/32″	1/16″
26	9/32″	1/32″	1/16″
28	9/32″	1/32″	1/16″
30	9/32″	1/32″	3/32″
32	5/16″	1/16″	3/32″

Next, to adjust the length of the dashport rods: turn the engine until the wrist plate has reached the extent of its travel in one direction, say the head end. Adjust the length of the dashpot rod so there will be an equal clearance around the catch block, i. e., between the block and the steel on the hook and on the other side between the block and the body of the hook. Turn the engine until the wrist plate is in the other extreme position and adjust the dashpot rod on that end in the same manner. THIS ADJUSTMENT IS ONE OF THE MOST IMPORTANT IN THE WHOLE SETTING, for if the dashpot rod is too short, the valve will not open; if it is left too long, the rod will be bent when the engine comes over, or the bonnets broken, or both.

The air valves on the dashpot should be adjusted after the engine is in operation, so that the dashpots do not drop too swiftly and slam, and yet drop quickly enough to give a sharp cut-off.

Next with the governor in its lowest position resting on the collar or pin provided for the purpose, turn the wrist plate so as to pick up the head end valve and then turn it over until it nearly reaches the

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mark corresponding to its opposite position. Then adjust the governor rod for the head end valve so that the trip block just engages the inner member of the hook, making sure that the valve will be released when the wrist plate reaches its extreme position. The same adjustment should now be made at the crank end of the cylinder. The governor should then be blocked up to its highest point of travel when the knock-off cam if used on the engine should be in such a position that neither valve can be lifted by the hook.

The setting should now be verified by an indicator.

Directions for Experiment

Set the valves on the Allis-Corliss as directed above. Have your instructor verify settings before replacing bonnets and again before starting the engine. Attach indicators to the cylinder.

After all settings are complete, start the engine according to the method of procedure outlined for the test of a Corliss engine.

Add load on the brake and take indicator cards. Adjust the valves to give the proper shape of card.

In your report outline how you set the valves.

Work up your data on the form shown for slide valve setting.

Experiment No. 12

TEST OF A CORLISS ENGINE

The object of this experiment is to study the effect of the Corliss valve gear on the economical use of steam.

The method of conducting this test is similar to that employed on both the simple throttling and high speed engines and need not be described in detail here.

At the end of the test one of the indicators should be removed and a condensation indicator with glass sides put in its place. The successive steps of cylinder condensation and re-evaporation can then be observed when the engine is in operation.

Run four twenty-minute tests at approximately ½, ¾, full load, and 1¼ loads. Plot the same curves as asked for in Experiment 7.

In conducting this experiment follow the general directions as outlined in Experiment 7, and report data on forms as given for the same experiment.

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Compare results with the results for the throttling and high speed engines.

The rated capacity of the engine is 30 i.h.p. at 100 r.p.m. Its cylinder is 8 in. x 24 in. and the piston rod diameter is $1\frac{9}{16}$ in. The brake arm is 4 ft. 0 in.

Experiment No. 13

NORDBERG ENGINE WITH SATURATED STEAM AND CONDENSING

The Nordberg engine is a cross compound unit fitted with poppet valves of which there is a steam and an exhaust valve for each end of the cylinder.

By the use of poppet valves the lubrication troubles met with on slide valves and Corliss valves are overcome. Poppet valves also permit highly superheated steam to be used, especially when the engines are provided with a tail rod and slipper which together with the cross head carries the weight of the piston thus making the wear on the cylinder very small.

The cylinder and cylinder heads are steam jacketed. Hence tests can be made on this engine with wet, dry saturated, or superheated steam, with or without steam in the jackets. The receiver between the two cylinders is also steam jacketed and may be used as a reheater. The exhaust steam passes from the bottom exhaust chest of the high pressure cylinder, through this receiver and up into the steam chest of the low pressure cylinder. The exhaust from the low pressure cylinder is carried to a surface condenser where it can be condensed in a vacuum. A wet air pump direct connected to the engine shaft by means of an eccentric, maintains the desired vacuum in the condenser. In a complete test of the engine the power required to drive this air pump should be credited to the engine together with the brake horsepower.

The engine cranks are set at 90° so as to produce an even torque on the shaft. Notice the built up flywheel on this engine.

The poppet valves are operated by eccentrics and levers from an auxiliary shaft whose axis is parallel to the axis of the cylinder. This shaft is driven from the main shaft through bevel gears.

The steam valves on the high pressure cylinder are under control of the governor which alters the point of cut-off automatically to suit

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the load on the engine. The cut-off on the low pressure cylinder is set by hand and is not controlled by the governor.

On each cylinder there are two openings on top for the steam valves and two below for exhaust valves. In both cylinders the steam chest runs the full length of the cylinder and is about equal in width to the diameter of the cylinder. Its internal height on the high pressure cylinder is about 1¼ in. and on the low pressure cylinder about 2½ in. The exhaust chests are of similar dimensions and arranged in the same way on the under side of both cylinders.

The jacket space on the cylinder is formed by means of a core which completely surrounds the cylinder except on the top and bottom where a portion is partitioned off for the circular openings for the poppet valves. The steam chests and exhaust chests are outside this jacket core.

The receiver consists of a piece of 14 in. cast iron pipe 6 feet long. Inside of the iron pipe at each end is a steam header into which are rolled 76 copper tubes ⅝ in. in diameter and 54 inches long. The reheating steam is inside of the tubes and the exhaust steam from the high pressure cylinder surrounds the tubes.

Attached to the reheating receiver is a separator for removing the water of condensation from the steam after it leaves the high pressure cylinder and before it enters the receiver. A Dunham low pressure steam trap removes the condensation from the separator.

The receiver pressure can be varied by altering the cut-off on the low pressure cylinder. In general, the higher the receiver pressure the greater is the proportion of work done by the low pressure cylinder. By observing the position of the governor and altering the receiver pressure, the most economical cut-off on the low pressure cylinder can be easily determined. In practice it has not been found economical to divide the work equally between the high and low pressure cylinders. The high pressure cylinder generally does by far the greater proportion of the work.

The governor on this engine is of the Proell type and is provided with counterweights so that the number of revolutions of the engine can be varied from 90 to 125 per minute. The cut-off on the high pressure cylinder has a range of automatic variation from 0 to 90 per cent of the stroke.

The valve gear on this engine deserves close study for it is the only engine in the laboratory on which every event of the stroke can be altered without affecting the other events.

When the quality of the steam leaving the high pressure, or entering the low pressure is determined by a separating calorimeter, it

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does not necessarily follow that the readings have to be taken at five minute intervals, especially when the discharge steam is weighed. Readings can be taken throughout the test as found most convenient by the observer.

The following data applies to the Nordberg engine:

		High Press.	Low Press.
Diam. of cylinders		8 in.	13 in.
Stroke		20 in.	20 in.
Diam. of piston rods		1-15/16 in.	1-15/16 in.
Area of piston, sq. in.	Head—	50.35	132.8
	Crank—	47.35	129.8
Clearances, % of cylinder volume	Head—	8.55	9.2
	Crank—	9.14	8.2

Brake arm 60.5 inches.
Air pump plunger—7 in. diam. with 7 in. stroke.

Directions for Test

Follow general directions as outlined in Experiment No. 7.

Make a series of tests on the engine at such loads as determined by the instructor at the time of the experiment, taking five minute readings.

In running a test always note whether the cut-off is the same on both ends of the high pressure cylinder, and, if not, adjust the valve gear to make it the same.

Take data on the following forms.

The complete report following is derived from the A. S. M. E. code for testing engines. Should you be called on to conduct a test of importance on a steam engine of any size, it would be advisable to secure a copy of this code as it contains much valuable information regarding the conducting of an engine test.

In your final report plot curves with i.h.p. as abscissae and with total steam, pounds of steam per i.h.p.-hour, thermal efficiency, efficiency ratio based on Rankine cycle and mechanical efficiency as ordinates. Also plot curves with br.h.p. as abscissae and with pounds of steam per br.h.p.-hour as ordinates.

Calculate the "per cent" vacuum for each test.

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Log of Indicator Cards

Cards from.....Engine
Date.....
Dead weight on brake.....

Scale of springs, High pressure.....
Diameter of cylinder " " .....
Diameter of piston rod" " .....
Piston area, high pressure, {head..... crank .....

Observers.....
Barometer.....
Length Brake Arm, ft.....
Length of stroke.....

Low pressure.....
" " .....
" " .....
Low pressure, {head ..... crank .....

Time	r.p.m.	High Pressure					Low Pressure					Net i.h.p.	Brake load	br. h.p.
		m.e.p.		i.h.p.		Total	m.e.p.		i.h.p.		Total			
		Head	Crank	Head	Crank		Head	Crank	Head	Crank				

Engine Log

High Pressure Cylinder

Diameter of cylinder.....
Length of stroke.....
Barometer.....
Observers.....

Low Pressure Cylinder

Diameter of cylinder.....
Length of stroke.....
Date of test.....

Time	Speed		Pressure				Temperature									Weight	
	Continuous counter	r.p.m.	Steam	Receiver	Condenser	Back pr's. in calorimeter	External air	Engine room	Condensed steam	Exhaust high pres.	Admission L. P.	Steam line	Calorimeter	Injection water	Discharge water	Condensed steam	Injection water

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TEST OF.....COMPOUND ENGINE

(1) Test of.....engine located at.....
To determine.....
Test conducted by.....
(2) Type of engine (simple or multiple expansion).....
(4) Auxiliaries (steam or electric driven).....
(a) Type and make of condenser equipment.....
(5) Rated power of engine.....

		1st	2d
(6)	Diameter of cylinders	in.	
(7)	Stroke of pistons	ft.	
	(a) Diameter of piston rod, each end	in.	

(13) Pressure in steam pipe near throttle
(a) Gage.....lb. per sq. in.
(b) Absolute.....lb. per sq. in.
(14) Barometric pressure.....in. of mercury
(15) Pressure in 1st receiver
(a) Gage.....lb. per sq. in.
(b) Absolute.....lb. per sq. in.
(18) Vacuum in condenser.....in. of mercury
(19) Pressure in jackets and reheaters
(a) Gage.....lb. per sq. in.
(b) Absolute.....lb. per sq. in.
(20) Temperature of steam near throttle.....deg.
(a) Temperature of saturated steam at throttle pressure.....deg.
(b) Temperature of steam leaving 1st receiver, if superheated.....deg.
(21) Temperature of steam in exhaust pipe near engine.....deg.
(22) Percentage of moisture in steam near throttle or number of degrees of superheating.....per cent or deg.
(24) Total condensed steam from surface condenser (corrected for condenser leakage).....lb.
(25) Total dry steam consumed by cylinders.....lb.
(a) Total dry steam consumed by jackets.....lb.
(27) Total dry steam consumed for all purposes per hour.....lb.
(29) (a) Circulating water supplied to condenser per hour.....lb.
(b) Pounds of cooling water per pound of steam condensed.....lb.
(30) Heat units consumed by engine per hr.....
(a) Total heat units supplied to cylinders per hr.....B.t.u.
(b) Heat converted into work per hour.....B.t.u.
(c) Heat absorbed by condenser per hr.....B.t.u.
(d) Heat consumed by jackets.....B.t.u.
(e) Heat lost in condensed steam per hr.....B.t.u.
(f) Heat lost by radiation per hr.....B.t.u.

INDICATOR CARDS

(31) Commercial cut-off in per cent of stroke.....per cent.....
(32) Initial pressure above atmosphere.....lb. per sq. in.....
(33) Back pressure at lowest point above or below atmosphere.....lb. per sq. in.....
(34) Mean effective pressure.....lb. per sq. in.....
(a) 1st cylinder.....lb. per sq. in.....
(b) 2d cylinder.....lb. per sq. in.....
(37)
(a) Pressure at selected point near cut-off.....lb. per sq. in.....
(b) Pressure at selected point near release.....lb. per sq. in.....
(c) Pressure at point on compression curve shortly after exhaust closure.....lb. per sq. in.....
(d) Proportion of direct stroke completed at selected point near cut-off.....
(e) Proportion of direct stroke completed at selected point near release.....
(f) Proportion of return stroke uncompleted at selected point on compression line.....
(38) Revolutions per minute.....r.p.m.
(40) Indicated h.p. developed, whole engine.....i.h.p.
(a) i.h.p. developed by 1st cylinder.....i.h.p.
(b) i.h.p. developed by 2d cylinder.....i.h.p.
(41) Brake h.p.....br.h.p.
(43) Dry steam consumed by engine per i. h. p. per hr.....lb.
(a) Engine cylinders.....
(b) Jackets.....
(c) Engine including jacket and auxiliaries.....
(47) Heat units consumed by engine and auxiliaries per i.h.p.-hr. (Item 30÷Item 40).....B.t.u.
(48) Heat units consumed by engine and auxiliaries per br. h.p.-hr. (Item 30÷Item 41).....B. t. u.
(49) Thermal efficiency of engine referred to i.h.p. [(2546.5÷Item 47)x100].....per cent
(a) Mechanical efficiency.....
(51) Efficiency of Rankine cycle between temperatures of Items 20 and 21.....
(52) Rankine cycle ratio referred to i.h.p. (Item 49÷Item 51).....

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Experiment No. 14

TEST OF NORDBERG ENGINE WITH SATURATED STEAM AND NON-CONDENSING

This test is conducted exactly the same as Experiment No. 13 with the exception that the engine is operated non-condensing instead of condensing.

The object of the test is to determine the economic results of a cross-compound engine operating noncondensing and to compare the results with the results of the same engine operating condensing with and without superheated steam.

In order to run noncondensing, the compression in the cylinders must be changed and the pressure in the receiver must be increased. Instructions regarding receiver pressures will be given at the time of performing the experiment.

Experiment No. 15

NORDBERG ENGINE WITH SATURATED STEAM AND WITH STEAM JACKETS, CONDENSING

See Experiment No. 13 for description of the engine and general directions for carrying out the test.

All the steam jackets are fitted with receivers into which the condensed steam drains. These receivers are provided with gage glasses so that the height of the condensed steam can be observed.

Tubs filled with a known weight of cold water are placed so that the end of the pipe leading from the bottom of the receiver is submerged. This pipe is provided with a valve so that the condensed water can be blown out from time to time. This cold water is necessary because the condensed steam in the receivers is at the same temperature as the steam supplied and if blown into the atmosphere there would be a considerable loss through evaporation.

At the beginning of the test the receivers should be blown down into spare tubs to some fixed level, such as a string tied to the gage glass. Then the tubs with cold water can be put in place. At the end of the tests the receivers should be at the same level as at the start. The increase in the weight of the tubs represents the steam

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condensed in the jackets in overcoming radiation and in heating the cylinder walls.

In calculating the thermal efficiency when steam jackets are used, the engine should be charged with the total heat above the heat of the liquid at exhaust pressure in the steam passing through the cylinders, together with the heat of vaporization or latent heat only of the steam passing through the jackets. This is apparent because the condensed steam is discharged from the jackets at the same temperature as the steam line.

Except for measuring the jacket steam, the observations are the same as those noted in the preceding test. The same log form and form of general report will also be used. Also plot the similar sets of curves to those called for in the preceding experiment.

Experiment No. 16

NORDBERG ENGINE WITH SUPERHEATED STEAM

The jackets are not used in these tests and the temperature instead of the quality of steam at entrance is determined. The temperature of the steam entering the low pressure cylinder is also determined.

In order to carry out this experiment, it is necessary to start the engine and run it for some time under load while the superheater is being fired up and put in operation. During the test great care must be taken to keep the temperature of the steam leaving the superheater within the limits of the apparatus. When the tests are over the fires must be drawn from the superheater and the engine must be kept running under load until the temperature of the steam leaving the superheater has been reduced to that of saturated steam. Any other method of procedure is liable seriously to damage the superheater.

When tests are run with superheat on the engine, a special grade of cylinder oil, suitable for superheat, must be used in the lubricators of both high and low pressure cylinders.

It will be noted that the cut-off on the high pressure cylinder is much later with the same loads than when saturated steam was used considering the relative amounts of condensed steam in the two cases. In your report explain this apparent contradiction of results.

Make a series of tests with superheat at such loads as may be designated by the instructor.

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Use the data sheets and general report form, and plot similar curves to those required in test No. 13 with saturated steam.

Also plot a series of curves for the three tests with saturated steam without and with jackets, and with superheat, showing br. h.p. as abscissae and pounds of steam per br. h.p. hour, thermal efficiency, and efficiency ratios as ordinates. Comment on these curves and draw conclusions as to the most efficient method of running the Nordberg engine.

Experiment No. 17

CLAYTON'S ANALYSIS OF CYLINDER PERFORMANCE

In a paper before the American Society of Mechanical Engineers in 1912, Mr. J. Paul Clayton of the University of Illinois presented a new method of analyzing indicator diagrams. He found in his experiments that the expansion and compression of steam in the cylinders of reciprocating engines take place substantially according to the law ($P V^n = C$) where the values of n may vary from 0.70 to 1.35. Where such a curve is plotted on logarithmic cross-section paper it becomes a straight line.

From the fact that the equation ($P V^n = C$) holds for the expansion and contraction curves of steam indicator diagrams, Mr. Clayton developed rational methods of approximating the clearance volume, of closely locating the cyclic events, and of detecting moderate amounts of leakage by the simple rise of such an indicator diagram taken at any time when the engine is in operation.

To apply this method in the laboratory, it is advisable to select cards from an engine in which the weight of condensed steam, the number of revolutions per minute, and the barometer readings are at hand. A check can then be made on Clayton's method. The cards should be taken at the same time on both ends of the cylinder. It is best to take a set of cards and select those representing average conditions for the test. Each card must be very accurately planimetered. Draw in the absolute zero pressure lines on both cards.

The first step is to determine the clearance at each end of the cylinder. From the type of engine it is possible to estimate fairly closely the percentage of the piston displacement that the clearance occupies. Assume four values of the percentage clearance, some larger and some smaller than the estimated clearance. Make up a table of the absolute volumes of steam present in the cylinder at a

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series of about six pressures on both the expansion and the compression lines of each card. Lay on logarithmic cross-section paper a P V diagram of the expansion and compression lines for head end. On the logarithmic diagram, the absolute pressures of each of these points will remain constant while the absolute volumes will vary. Mr. Clayton has shown that the expansion line becomes straight when plotted in such a manner with the correct clearance. Hence select that clearance which gives the expansion and compression lines that are more nearly straight or interpolate between those lines which are more nearly straight. The same method is then followed on the crank end card. In laying out such a diagram, it may be necessary to paste four sheets of logarithmic paper together unless sheets can be obtained with two scales of 0-10 on each side. When the proper clearance is decided upon the remainder of the diagram may be plotted. The clearance volumes may be found by this graphical method to within 5 per cent to 10 per cent of the clearance volume, depending as the clearance itself varies from 20 per cent to 2 per cent of the piston displacement.

To find the value of "n" for expansion line:

Take any two points on the expansion line and let these be P_1, V_1 and P_2 V_2. From the law ($P V^n = C$) it follows that,

$$P_1 V^n_1 = P_2 V^n_2$$

Taking logarithms of both sides, we find

$$n (\log V_1 - \log V_2) = \log P_2 - \log P_1$$

$$n = \frac{\log P_2 - \log P_1}{\log V_1 - \log V_2}$$

Now on the diagram ($\log P_2$—$\log P_1$) represents the vertical between the two points and ($\log V_1$—$\log V_2$) is the horizontal ordinate. Hence "n" is the slope of the line and thus can be easily found from the plotted diagrams.

To find the quality at cut-off:

The point of cut-off is the point where the admission of steam is stopped by the closing of the valve. It is difficult to determine the exact point at which cut-off takes place. It is usually located where the line on the diagram changes its curvature from concave to convex at the beginning of expansion.

The new A. S. M. E. rule regarding cut-off reads as follows: "To find the percentage of cut-off, or what may best be termed the commercial cut-off, the following rule should be observed. Through the

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point of maximum pressure during admission draw a line parallel to the atmospheric line. Through a point on the expansion line where the cut-off is complete, draw a hyperbolic curve. The intersection of these two lines is the point of commercial cut-off and the proportion of cut-off to stroke is found by dividing the length measured on the diagram up to this point by the total length." Mr. Clayton does not indicate which of these cut-offs to use in his method of analysis, although he probably used the former. However, in the laboratory try both cut-offs and see which is more nearly correct.

It is well known from thermodynamics that the quality of the steam at cut-off is very much lower than at the throttle valve owing to cylinder condensation phenomena during admission. Mr. Clayton has shown that there is a fixed value for "Xc" the quality of steam at cut-off, for every value of "n" and "P" the absolute pressure at cut-off, and he has plotted these results in the form of curves, which are available in Mr. Clayton's paper in *Journal of A. S. M. E.*, April, 1912; in Vol. 34, *Trans. of A. S. M. E.*; in *Bulletin 58* of the University of Illinois.

The specific volume of one pound of dry steam at cut-off pressure may be obtained from the steam tables. When this volume is multiplied by "X c" the actual volume of one pound of steam under cut-off conditions of absolute pressure and quality may be obtained. The total volume of steam in the cylinder at cut-off can be determined from the diagram and by dividing this by the actual volume of one pound, the total weight in the cylinder at cut-off can be calculated. But this weight includes the weight of the steam remaining in the cylinder when the exhaust valve closes and compression commences. This compression steam must be deducted from the total weight at cut-off in order to obtain the net weight of steam passing through that end of the cylinder per stroke.

A careful investigation made by George Duschane at Liége, Belgium, indicates that when saturated steam is used the steam in the cylinder is dry or even slightly superheated at the closure of the exhaust valve. It has been shown by logarithmic diagrams, that leakage of the steam in compression continues until the exhaust valve in closing has acquired considerable seal. The point usually selected for calculation of the compression steam is at or near the beginning of compression and nearly always accounts for more steam than was actually retained. The following method has heretofore been adopted to find the weight of this steam.

The straight compression curve on the logarithmic diagram is continued as a dotted line to intersect the back pressure or its ex-

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tension. The point of intersection of these two lines is taken as the volume of dry steam retained in compression at absolute back pressure. The volume of one pound of dry steam at this absolute pressure can be found from the steam tables and thus the weight of steam in compression can be calculated.

The sum of the net weights of the steam passing through the cylinder, as shown by the head and crank end cards is next multiplied by the number of revolutions per hour. The result gives the total steam consumption per hour and if the test has been performed correctly this should check the weight of steam discharged from the condenser within 4 per cent.

The total indicated horsepower can be calculated from the m.e.p. of the diagrams and the steam consumption per indicated horsepower hour can be computed.

In order to obtain accurate results by means of this analysis, the reducing motion must be correct and the strings must not stretch. The scale of the springs in the indicators at pressures in the neighborhood of the point of cut-off must be ascertained with great accuracy. It is therefore necessary in this test to calibrate the springs in the laboratory indicator tester.

Detection of leakage.

It is seldom found that leakage does not occur in a cylinder and that only one source of leakage exists. Leakage is usually the result of wear which affects most of the possible sources of leakage in about an equal proportion. In discussing leakage it must be kept in mind that difference in pressure between two regions is the cause of this phenomena. There are three pressures that must be considered, viz., the pressure in the steam chest, that in the cylinder at the point discussed and that in the exhaust passage. Leakage being due to difference of pressure, becomes material only when this difference become considerable. Thus leakage into or out of a cylinder has been found to occur in most cases when the pressure difference is over 20 lb.

This fact enables us to divide the expansion and compression lines roughly into three equal parts on the logarithmic diagram (when these lines extend from the initial pressure to nearly the back pressure). (1) The upper third influenced by leaks out from the cylinder, (2) the middle third practically uninfluenced by leakage, and (3) the lower third influenced by leakage into the cylinder. Thus fairly reliable values of "n" free from the effects of leakage may be obtained from the middle third of the lines. The volume in the cyl-

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inder is increased or decreased as steam leaks into or out of the cylinder.

The errors that one is liable to encounter in applying this analysis to engines are principally as follows: (a) Wrong clearance or wrong location of the zero line of pressure, (b) wrong location of cut-off, (c) leakage past piston or valves and (d) low speed of steam engine.

After a little practice, it should be possible for an engineer to place indicators on an engine cylinder, take sets of cards at a number of loads from no load to full load and from these cards estimate accurately the same consumption of that engine at each load as well as to discover any leakage that may take place.

References:—

Journal A. S. M. E., April, 1912.
Transactions A. S. M. E., Vol. 34.
Univ. of Ill. Bulletin 58.
Univ. of Ill. Bulletin 65.
Power, 1912, criticisms of this method.

Experiment No. 18

CURTIS STEAM TURBINE TEST

The Curtis steam turbine is of the impulse type provided with velocity stages. It is used principally for supplying power to electric generators which are direct connected to the turbine. The axis of the shaft may be horizontal or vertical.

The set in the laboratory consists of a Curtis horizontal steam turbine, direct connected on the same shaft to a 25 K. W. compound wound General Electric direct current generator. The turbine is of the single stage, noncondensing type with three sets of bucket wheels mounted on the same hub. Between these revolving bucket wheels are the intermediate or stationary buckets. The nozzles are contained in a separate casting, which bolts on the front of the casing. Steam is admitted through a separator to the steam chest and passes through a balanced piston valve operated by the governor, directly to the steam nozzles.

The heat given up by the steam due to its drop of pressure through the nozzles, is transformed into kinetic energy and increases the velocity of the steam. On leaving the nozzles, the steam impinges on the first row of moving buckets at a very high velocity. Part of the

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kinetic energy is absorbed by this row of buckets and converted into work. After leaving this first bucket wheel, the steam is redirected by a row of stationary guide buckets onto the second revolving bucket wheel, which absorbs more of the kinetic energy. Similar action takes place in the second set of guide buckets and the third set of revolving buckets. The steam then has parted with practically all its velocity and passes out the exhaust.

The governing mechanism consists of a small spring fly-ball governor mounted on the shaft of the turbine itself and rotating with it. This governor through a suitable bell crank controls a small balanced piston valve which regulates the amount of steam being supplied to the nozzles.

The set is equipped with two bearings, the turbine being overhung. The main bearing is made in halves and is self-aligning in the pillow block. Washers are used to take up the end thrust, the washer next to the bearing being held stationary by dowel pins. The generator end bearing is made in one piece and is also self-aligning.

Lubrication is obtained by means of a gear pump attached to the commutator end of the shaft and driven by a worm gear. Oil rings and chains are also provided as a means of emergency lubrication to prevent injury to the bearing in case of accident to the pump. Only heavy mineral oils should be used, of good quality and free from dirt, grit, and waste. An oil pressure of from 3 to 6 lbs. should be maintained and may be regulated by adjusting the relief valve of the oiling system.

The generator produces continuous current at 125 volts when running at 3600 r.p.m. Load is provided by passing the current through a water rheostat. The load can be adjusted by altering the distance between these plates. The amount of current passing through the water may be increased by adding a few handfuls of salt. The voltage is controlled by adjusting the field rheostat on the switchboard.

A small worm has been connected to the end of the generator shaft and meshes with a worm wheel with gear ratios of 1 to 100. A lever connects a pin placed eccentrically on this worm wheel, with the recording arm of a speed counter. The reading of the speed counter multiplied by 100 represents the actual number of revolutions of the turbine. By taking readings of this counter throughout the test, the average speed can be computed.

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Directions for Test

Connect a calorimeter and gage to the steam pipe for moist steam or a gage and thermometer for superheat. The condition of the entering steam can be determined from these.

Turn cooling water on the condenser.

Warm up the turbine casing by turning on a small amount of steam. Start the machine slowly under steam and see that the oil pump is working and distributing the oil properly. Bring gradually up to speed and see that oil is flowing at both bearings.

When the set has been brought up to speed and is running satisfactorily, close the field switch and see that the armature voltage builds up properly. Adjust the voltage to the proper amount. Spread the plates in the water rheostat as far apart as possible.

Close the circuit breaker and then close the main switch. Adjust the plates in the water rheostat, keeping the voltage constant on the field rheostat until the correct load is reached.

If the brushes on the commutator are chattering, wipe it lightly with a cloth pad moistened with vaseline or a little clean oil. Use any lubricant very sparingly.

Measure speed by taking readings from the continuous counter and check by two minute readings with a revolution counter.

Take readings for log every five minutes.

Run tests of 20 minutes each with loads of 6½ kw., 12½ kw., 18¾ kw., and 25 kw., on the generator, keeping records on the accompanying forms.

Figure out your tests and from the general results plot curves with e.h.p. as abscissae and total steam and lb. of steam per e.h.p. hour as ordinates.

The efficiency of the generator including windage and friction is about as follows:

Quarter load	73 %
Half load	81.7%
Three-quarter load	86 %
Full load	88 %
One and one-quarter load	88 %

Plot this efficiency curve with e.h.p. as abscissae.

The output of the generator is equal to the input multiplied by the generator efficiency. Hence the input to the generator or brake horsepower of the turbine must equal the output in electrical horsepower

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divided by the generator efficiency which can be determined from the curves already plotted.

Calculate the brake horsepower for each load and also the lb. of dry steam per br. h.p. hour and plot these results in a curve.

Plot curves between br. h.p. as abscissae and both thermal efficiency and efficiency ratios.

Compare the commercial efficiency with that obtained on the simple engine, the high speed, and the Corliss. It must be borne in mind that the larger sizes of turbines with several stages and operating condensing are much more economical than the smaller sizes and even equal in economy the best types of reciprocating engines.

The cooling water to the condenser is measured by a Venturi meter. The actual quantity of water passing through the meter can be found from the following fundamental equations:

$$\frac{P_1}{\alpha} + \frac{V_1^2}{2g} = \frac{P_2}{\alpha} + \frac{V_2^2}{2g}$$

$$\frac{V_1}{V_2} = \frac{A_2}{A_1}$$

$$Q = CA_1V_1 = CA_2V_2 = \frac{CA_1A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{\frac{2g\,(P_1 - P_2)}{\alpha}}$$

In the above equations P_1 = absolute pressure in lb. per sq. ft. before the meter where A_1 = area in sq. ft. and V_1 = velocity in ft. per sec.;

P_2 = absolute pressure in lb. per sq. ft. in the throat of the meter where A_2 = area in sq. ft. and V_2 = velocity in ft. per sec.;

Q = actual cu. ft. of water per sec. and

C = a calibration coefficient = .92

α = weight of water per cu. ft.

The diameter before the meter = 1½ in. and the diameter of the throat = ½ in.

In your preliminary report include the computations for finding the value of the constant K for this meter in pounds of water per hour in the formula

$$W = K\sqrt{p_1 - p_2}$$

where W = pounds of water per hour

$$K = \frac{CA_1A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{\frac{2g \times 144}{\alpha}} \times 3600 \times \alpha$$

p_1 and p_2 = pounds per sq. in. absolute

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Log of Curtis Steam Turbine Test

Date..... Barometer.....
Size of turbine..... Normal r.p.m.....
Volts at full load..... Amperes at full load.....
Observers..... .....

Time	Pressures			Continuous rev. counter	r.p.m.	Temperatures				Generator		Venturi-Meter		Weight of cond. steam	
	At throttle	Before nozzle	Calorimeter			Calorimeter	Condensed steam	Injection water	Discharge water	Volts	Amperes	Press. before meter	Press. in throat		

DATA AND RESULTS

(1) Test of.....turbine located at.....
To determine.....
Test conducted by.....
(2) Type of turbine (impulse, reaction, or combination).....
(a) Number of stages.....
(b) Condensing or noncondensing.....
(c) Diameter of rotors.....
(d) Number and type of nozzles.....
(e) Area of nozzles.....
(f) Type of governor.....
(5) Rated capacity of turbine.....
(a) Name of builders.....
(7) Date.....
(8) Duration.....
(9) Pressure in steam pipe near throttle by { gage.....lb. per sq. in. / absolute.....lb. per sq. in.
(10) Barometric pressure.....in. of mercury
(b) Pressure in steam chest by gage.....lb. per sq. in.
(11) Pressure in exhaust pipe near turbine, by { gage.....lb. per sq. in. / absolute.....lb. per sq. in.
(13) Temperature of steam near throttle.....deg.
(14) Temperature of steam in exhaust pipe near turbine.....deg.
(a) Temperature of circulating water entering condenser.....deg.
(b) Temperature of circulating water leaving condenser.....deg.
(c) Temperature of air in turbine room.....deg.
(15) Percentage of moisture in steam near throttle, or number of degrees of superheating.....per cent or deg.
(17) Total condensate from surface condenser (corrected for condenser leakage and leakage of shaft and pump glands).....lb.
(18) Total dry steam consumed.....lb.
(22) Dry steam consumed by turbine per hour.....lb.
(a) Circulating water supplied to condenser per hour.....lb.
(23) Heat units consumed by turbine per hour [Item 22 x (total heat of steam per pound at pressure of Item 9 less heat in 1 lb. of water at temperature of Item 14)].....B.t.u.
(a) Heat converted into work per hour.....B.t.u.
(b) Heat absorbed to condenser per hour (approx.).....B.t.u.
(c) Heat lost in condensed steam.....B.t.u.
(d) Heat lost by radiation from turbine, and unaccounted for.....B.t.u.
(24) Average volts.....volts
(25) Average amperes.....amperes
(28) Total kilowatts output.....kw.
(32) Revolutions per minute.....r.p.m.

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(33) Variation of speed between no load and full load.....r.p.m.
(35) Brake horsepower, if determined.....br.h.p.
(36) Electrical horsepower.....e.h.p.
(37) Dry steam consumed by turbine per br. h.p.-hr.....lb.
(38) Dry steam consumed per net kw-hr.....lb.
(39) Heat units consumed by turbine per br. h.p.-hr. (Item 23÷Item 35).....B.t.u.
(40) Heat units consumed per net kw-hr.....B.t.u.
(41) Thermal efficiency of turbine (2546.5÷Item 39)x 100.....per cent
(42) Efficiency of Rankine cycle between temperatures of Items 13 and 14.....per cent
(43) Rankine cycle ratio (Item 41÷Item 42).....
(44) Net work per B.t.u. consumed by turbine (1,980,000÷Item 39).....ft. lb.

Experiment No. 19

INJECTORS AND EJECTORS

The steam injector is an instrument designed for feeding water to steam boilers, although it is often used as a pump to raise water from one level to some other level. It may be modified and used as an air compressor and still another modification is the ejector condenser for condensing the exhaust of steam engines or turbines, in which case it takes the place of both air pump and condenser.

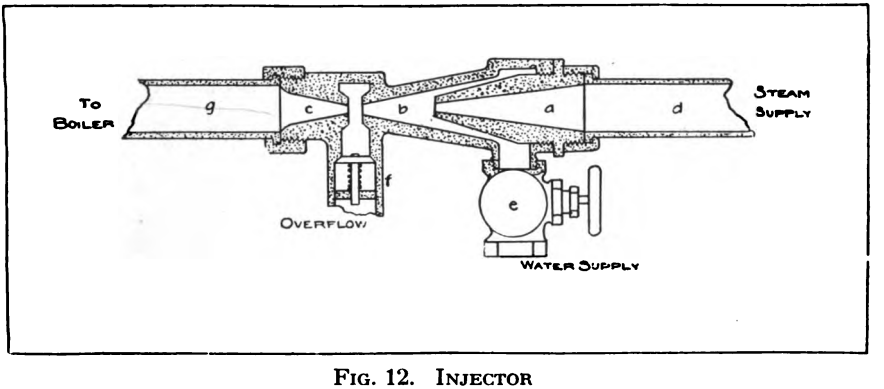

Fig. 12. Injector

Injectors are very generally used on locomotive boilers, on traction engines, and on small stationary boilers. They are made in two general classes, lifting and nonlifting. In the former class the water supply is below the level of the injector and work is done in raising the water in addition to that required to lift against a pressure. In the latter class the water is delivered to the injector under more or less pressure.

A simple form of injector is that shown in Fig. 12, which shows the essential features of all types. (a) is the steam nozzle, (b) the combining tube, and (c) the delivery tube. Steam is supplied through

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(d) and water through the pipe (e). These mingle in (b) and are forced out through (c) into the pipe (g), which leads to the boiler. The connection to the boiler must be provided with a check valve to keep hot water from working back into the injector. In starting up, water wastes through the overflow (f) until the velocity of the stream has become sufficient to overcome the head due to the pressure in the boiler.

The nonlifting type is provided with two injector tubes, one to lift the water and supply it to the second tube which delivers it to the boiler. These are known as double tube injectors.

It is not intended to give in these notes, the thermodynamic theory or the mechanics of the injector. The student is referred to Peabody's *Thermodynamics of the Steam Engine* or some similar book for such information. Briefly stated the action of the injector is as follows: Steam enters the steam nozzle (a) and attains a high velocity as it expands on leaving the outlet. The steam coming in contact with water as it enters the combining tube (b) is condensed. This condensation creates a partial vacuum at this point which maintains the inward rush of water. The condensed steam together with the entering water forms a solid mass which absorbs the kinetic energy of the steam due to its high velocity as it issues from the nozzle. Hence this mass of water starts down the combining tube at a continually increasing velocity until the throat is reached. By this time the steam has all been condensed. The water and condensed steam then enter the delivery pipe where its velocity energy is converted into pressure energy of sufficient magnitude to lift the check valve and allow the mass to flow into the boiler.

As a thermodynamic machine the injector is nearly perfect, since all the heat received by it, except a small portion lost in radiation, is returned to the boiler. Hence the thermal efficiency should almost reach 100 per cent in every case. Its mechanical efficiency, based on the work done in lifting water, is small compared to its thermal efficiency because its heat energy is principally used in warming up the cold water as it enters the boiler instead of doing mechanical work.

Let r_1 = heat of vaporization of a pound of dry steam, x_1 = the quality of the steam supplied the injector, q_1 = the heat of the liquid above 32 degrees F. all at the pressure of the entering steam, w = weight of steam per hour uncorrected for calorimeter determinations, W = the weight of the water supplied to the injector, t_1 = the temperature of the delivery to the boiler, and t_2 = the temperature of the water supply.

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Then we have the heat above 32 degrees F. of one pound of steam supplied equal to $(x_1 r_1 + q_1)$.

If the mechanical work consists of W pounds of water lifted N feet by pressure and s feet by suction, the heat equivalent (F) of the mechanical work is

$$F = A\,[(n + s)\,W + wn], \text{ where } A = \frac{1}{778},$$

if the water is delivered from the discharge pipe without sensible velocity. In case there is a velocity of v ft. per sec. at delivery from the discharge pipe, the energy due to velocity in heat units is

$$L = \frac{A\,(W + w)\,v^2}{2g}$$

The heat units taken up by the feed water are

$$K = W\,(t_1 - t_2).$$

The thermal efficiency E if the injector is used for feeding boilers is

$$E = \frac{F + L + K}{w\,(x_1 r_1 + q_1 - q_2)}$$

where q_2 = heat of discharge water above 32 degrees F. If the injector is used as a pump, the heat K received by the discharge water is to be neglected, and the efficiency Ep is

$$Ep = \frac{F + L}{w(x_1 r_1 + q_1 - q_2)}$$

The velocity of the steam issuing from the nozzle does not vary greatly from 1400 ft. per sec. under the conditions in which it is used in the injector. The velocity of water either in the suction, water passage of injector, or discharge, may be found by dividing the volume in cu. ft. per sec. passing the given cross section by the area of the cross section in square feet. The areas of the standard pipes and fittings may be taken from a table giving internal areas of pipes, etc.

The general method of starting injectors is as follows: Open the overflow and the water supply. Turn on steam until water appears at the overflow and the temperature of the injector is sufficiently low to condense the steam. Then close the overflow and the injector should discharge against a pressure equal to or greater than the steam pressure. In many of the injectors, the overflow valve will open whenever the pressure in the injector becomes greater than that of the atmosphere. In several makes, the overflow is closed by a valve

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regulated independently or connected by a lever to the starting handle so that it can be opened and closed at the proper time by the simple operation of admitting steam.

As the overflow is usually open to the atmosphere, the temperature of the jet cannot exceed 212 degrees F. It is seldom higher than 170° F. The temperature of the entering water must be low enough to condense the steam from the steam nozzle or the injector will not work. As the initial temperature of the feed water is increased, the weight of steam required to lift a given weight of feed water increases.

An injector will not feed water into boilers at 100 lb. gage pressure if the temperature of the supply is higher than about 110° F.

A variation of the steam pressure with a given setting of the injector requires a corresponding variation in the supply of water needed. If the steam pressure is increased, the supply of feed water should increase also to condense the steam properly, or the degree of vacuum will be reduced and the action of the injector will be impaired. Or if the pressure of the steam is reduced, the feed water will be in excess and will escape through the overflow. Hence with changed conditions in the steam line, it is necessary to manipulate the valves on the steam or water supply to get the best results from the injector.

Injectors will not work with oily or dirty water and are liable to be stopped up with anything that will not pass the nozzle. The use of red lead on pipe joints should be avoided in connecting up injectors.

A modification of the standard injector is the form known as the steam ejector. These are very commonly used for such work as priming centrifugal pumps, lifting water from sumps, etc. In the ejector, the steam leaves the nozzle at a high velocity and yields a portion of that velocity to a greater mass of air or water which is suitably directed into the path of the jet of high velocity and thus is lifted against some higher head. Water under pressure is often used in the jet in place of steam. An example of a water ejector used as an air pump is found in the laboratory in the apparatus used to maintain the vacuum for testing vacuum gages.

A boiler horsepower is approximately equivalent to 30 lb. of water per hour evaporated into steam at 100 lb. per sq. in. gage pressure from a feed water temperature of 70° F. The capacity of an injector in boiler horsepower thus can be roughly approximated by dividing the total weight of water supplied by 30.

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Directions for Testing

The injector testing plant consists of two tanks on platform scales and fitted with calibrated gage glasses. An injector draws water from one tank and delivers it into the other.

To start the experiment the supply tank is completely filled with water. The injector is then put in operation, drawing water from the supply tank and delivering it into the discharge tank, and the length of time is recorded for a certain amount of water to be pumped from one tank into the other. The difference between the two weights of water is the amount of steam used by the injector. Take readings every five minutes.

The valve on the discharge side of the injector should be set to give the discharge pressure required. Record on proper forms the pressure of the steam supply and the discharge, the quality of the steam, the temperature of the inlet and outlet water from the injector, and the amount of water handled.

Place vacuum gage on suction side of injector to measure any pipe friction loss.

Make runs with the discharge pressure ¼, ½, ¾, 1½ times the steam pressure.

Plot curves with thermal and mechanical efficiencies as ordinates and discharge pressures as abscissae.

State where you would look for trouble should the injector fail to work.

Report results on accompanying forms.

Injector Test

Make of injector..... Barometer.....
Diam. suction pipe..... Diam. steam orifice.....
Diam. discharge pipe..... Diam. water orifice.....
Date..... Observers.....

No. of test	Time	Gage Pressure			Back pressure in calorimeter	Head—Feet		Temperature				Lb. of Water	
		Steam supply	Delivery	Suction		Discharge	Suction	Supply	Discharge	Calorimeter	Room	Supplied	Delivered

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DATA AND RESULTS OF INJECTOR TEST

Make of injector..... Area of steam orifice.....
Area of water orifice..... Date of test.....
Diameter suction pipe..... Diameter discharge pipe.....
Observers.....

1.	Test No.....			
2.	Duration of test.....			
3.	Barometer inches of mercury.....			
4.	Pressure steam supply, lb.....			
5.	Discharge head, ft.....			
6.	Suction head, ft.....			
7.	Water supplied per hr., lb.....			
8.	Water delivered per hr., lb.....			
9.	Wet steam per hour, lb.....			
10.	Quality of steam, per cent.....			
11.	Dry stream per hr., lb.....			
12.	Steam pressure on injector lb. absolute.....			
13.	Cu. ft. of steam per hr. (calculated).....			
14.	Velocity of steam in nozzle, ft. per sec.....			
15.	Temperature of water supply, degrees F.			
16.	Temperature of water delivered, degrees F.....			
17.	Weight of water supplied, lb.....			
18.	Lb. of water per lb. wet steam.....			
19.	" " " " " dry steam.....			
20.	Cu. ft. of water delivered per hr.....			
21.	Velocity of water in nozzle, ft. per sec.....			
22.	Velocity of water in discharge pipe, ft. per sec.....			
23.	Heat equivalent of work delivered per hr., B.t.u.....			
24.	Heat absorbed by injection water per hr., B.t.u.....			
25.	Heat equivalent to velocity of discharge, B.t.u.....			
26.	Heat energy in steam per hour, B.t.u.....			
27.	Thermal efficiency, per cent.....			
28.	Thermal efficiency of injector as a pump, per cent.....			
29.	Capacity in boiler h.p.....			
30.	Capacity in mechanical h.p.....			
31.	Lb. of steam per h. p. hr. of work.....			
32.	Duty in ft. lb. per 1,000 lb. steam.....			
33.	Duty in ft. lb. per 1,000,000 B.t.u.....			

EXPERIMENT NO. 20

BOILER FEED PUMP AND HEATER TEST

In power plants of medium and large size, feed water is usually pumped into the boilers by a steam pump known as a Boiler Feed pump. This may consist of only a single steam and a single water cylinder opposite one another with both pistons on the same piston rod, or there may be two or more sets of water and steam cylinders. The pump is said to be a "duplex" when it has two sets of steam and water cylinders side by side and so arranged that the piston rod of one set moves the steam valve gear of the other set. In large installations the boiler feed pump may embody all the requirements of steam engine design, including cut-off valve gear, flywheel, etc.

In some plants motor driven three-throw pumps are used for boiler feed pumps. In many new plants of large size, small steam turbine-driven centrifugal pumps are becoming popular for this work.

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In single and duplex pumps, steam is not used expansively in the cylinder. It enters the cylinder at boiler pressure and as the valve remains open throughout the whole stroke, it does work by reason of its pressure which continues equal to the initial pressure.

When the piston reaches the end of its forward stroke the exhaust valve opens and remains open throughout the whole of the return stroke, making the back pressure practically that of the atmosphere. Hence the indicator card is almost rectangular with neither expansion or compression. It is apparent that the pump alone is a very uneconomical piece of machinery. It will be shown later how the exhaust steam can be used to great advantage in heating the feed water.

The feed water may be obtained from the hot well of a condenser where its temperature will range from 80° F. to 120° F. or it may come from some cold water supply. It is not usual to heat the feed water to more than about 200° F. to 210° F. in ordinary practice.

When cold feed water is supplied to a boiler, stresses are set up in the portions of the shell with which it comes in contact. Hence this is another reason why the water should be heated as much as possible before feeding to the boiler.

The test in the laboratory will be made to determine the efficiency of a simple pump alone used as a boiler feed pump and the efficiency of the combined pump and closed feed water heater.

The pump to be tested consists of one steam and one water cylinder. Indicators should be attached to take cards from both ends of each cylinder and suitable reducing motions provided. Provision should also be made to measure the length of the stroke which is liable to vary. Attach gages to read the suction and the discharge pressures, which latter may be regulated by means of a valve.

Measure the volume of water discharged by the pump. The "slip" is the name applied to the ratio of the difference between the actual volume delivered and the total piston displacement, to the total piston displacement. This loss is due to leakage past the piston valves, etc.

In an actual plant, the heater is usually supplied with exhaust steam from all auxiliaries such as exciters, condenser pumps, feed pumps, etc., and the amount of this steam is generally several times that used by the feed pump alone.

The heater used for this test is a small surface condenser containing 64 tubes 66 in. long, each tube $\frac{5}{8}$ in. outside diameter and $\frac{1}{2}$ in. inside diameter. It contains 57.6 sq. ft. of heating surface. Its outside radiating surface is approximately 16.5 sq. ft.

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The pump to be tested has a steam cylinder of 8 in. diameter and a water cylinder of 5 in. diameter. The common piston rod is $1\frac{3}{8}$ in. in diameter. The tail rod on the steam end is $\frac{9}{16}$ in. in diameter. The stroke varies up to 12 in., but should be measured every five minutes.

The thermal efficiency of the pump alone can be expressed in the usual way. The thermal efficiency of the heater cannot be found so easily as it is hard to determine the condition of the steam entering the heater. As there is no expansion in the pump, this may be slightly superheated on exhaust. The pressure and temperature of the exhaust should be taken. However, if this shows saturated steam, the quality of the exhaust may be approximated as 99 per cent and the heater charged with the heat in the steam at this condition above the heat over 32° in the feed water entering the heater. The efficiency of pump and heater combined

$$= \frac{\text{Heat turned into work} + \text{heat absorbed by heater}}{\text{Total heat in steam entering pump} - \text{heat in feed water above } 32^{\circ}}$$

Measure the inlet and outlet temperatures of the water passing through the heater and its weight or volume. From these observations, the B.t.u. taken up by the heater can be calculated.

Run one 60 minute test with a discharge pressure on the pump of .....lb. per sq. in. Take indicator cards off both cylinders and all other observations every five minutes.

Describe with sketch the reducing motion provided for taking indicator diagrams.

Note and describe the valve gear of this pump.

Boiler Feed Pump and Heater Test

Forms for report

Log of Pump Test

Kind of pump..... Mfg. by.....
Barometer..... Date of test.....
Size of pump..... Observers.....

Time	Pressure			Calorimeter		Strokes per minute	Length of stroke	Suction in feet	Steam		Water		Water pumped, lb.
	Steam gage	Suction gage	Delivery	Back pressure	Temperature				Head	Crank	Head	Crank	
									m.e.p.	m.e.p.	m.e.p.	m.e.p.	

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Log of Heater Test

Kind of heater..... Mfg. by.....
Barometer..... Boiling point for barometer pres.....
Date of test..... Observers.....

Time	Temperatures				Pressure in exhaust	Weights		Temperature of room
	Entering water	Discharge water	Condensed steam	Steam in exhaust		Condensed steam	Feed water	

Test of Boiler Feed Pump and Heater

Date of Test..... Observers.....

Report of Heater Test

1. Kind of heater.....
2. Mfg. by.....
3. Barometer.....
4. Boiling point due to barometric pressure.....
5. Number of tubes.....
6. Diam. of tubes.....
7. Length of tubes.....
8. Sq. ft. of heating surfaces.....
9. Test No.....
10. Duration, min.....
11. Steam pressure, gage.....
12. Steam pressure, absolute.....
13. Total weight condensed steam, lb.....
14. Total weight feed water, lb.....
15. Temperature discharge water, t_d — °F.....
16. Temperature entering water, t_e — °F.....
17. Temperature of condensed steam, — °F.....
18. Temperature of steam in heater, — °F.....
19. B.t.u absorbed per lb. water.....
20. Total B. t. u. absorbed by water.....
21. Average temperature of water in heater, — °F.....
22. Difference of temperature (average above) and steam, — °F
23. B.t.u. absorbed per sq. ft. of h. s. per deg. difference in temperature per hr.....
24. Radiation per sq. ft. outside surface per hr. B.t.u.....
25. Per cent decrease work in boiler, at steam pressure to pump due to heating feed water.

$$\text{Per cent} = 100\left(\frac{t_d - t_e}{xr + q - (t_e - 32)}\right)$$

where x at boiler = .99, r = latent heat, and q = heat of liquid at steam line pressure to pump.

Data and Results Boiler Feed Pump Tests

29. Kind of pump.....
30. Made by.....

Dimensions

31. Diameter of steam cylinder, —— in.....
32. Diameter of piston rods, —— in.....
33. Areas of steam pistons, head, —— sq. in.....
    crank, —— sq in.....
34. Strokes of steam piston.....
35. No. of steam pistons.....
36. No. of water pistons.....
37. Diameter of water pistons, —— in.....
38. Diameter of piston rods, —— in.....
39. Area of water pistons, head, —— sq. in.....
    crank, —— sq. in.....

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STEAM

40. Total steam supplied, —— lb.....
41. Total steam supplied per hr., —— lb.....
42. Quality of steam, —— per cent.....
43. Dry steam per hr., —— lb.....
44. Steam line pressure, gage, —— lb.....
45. Barometer, —— inches of mercury.....
46. B.t.u. per lb. of steam supplied.....

WATER

47. Delivery pressure, gage, —— lb.....
48. Suction pressure, gage, —— lb.....
49. Correction for location of gages, —— lb.....
50. Total head, —— feet.....
51. Total volume delivered, —— cu. ft.....
52. Total weight delivered, —— lb.....
53. Weight per hr., —— lb.....
54. Plunger displacement during test, —— cu. ft.....
55. Water horsepower from weight and head .....

STEAM CARDS

56. Scale of springs, head —— lb.....
crank —— lb.....
57. Absolute admission pressure, head —— lb.....
crank —— lb.....
58. Absolute back pressure, head —— lb.....
crank —— lb.....
59. Mean effective pressure, head —— lb. per sq. in.....
crank —— lb. per sq. in.....
60. Strokes per minute.....
61. I.h.p. —— head.....
crank.....
62. Total i.h.p.....

WATER CARDS

63. Scale of spring, head —— lb.....
crank —— lb.....
64. Suction pressure, head —— lb.....
crank —— lb.....
65. Delivery pressure, head —— lb.....
crank —— lb.....
66. Mean effective pressure, head —— lb. per sq. in.....
crank —— lb. per sq. in.....
67. Strokes per minute.....
68. Indicated h.p. head.....
crank.....
69. Total i.h.p.....

HEAT BALANCE

70. B.t.u. per lb. steam supplied.....
71. B.t.u. equivalent to work per lb. of steam supplied.....
72. B.t.u. absorbed by heater per lb. of steam supplied.....
73. B.t.u. loss in radiation per lb. of steam supplied.....
74. B.t.u. loss in condensed steam per lb.....
75. Wet steam per i.h.p. hr. —— lb.....
76. Dry steam per i.h.p. hr. —— lb.....
77. B. t. u. per i.h.p. hr.....
78. Duty, ft. lb. per million B.t.u. supplied.....
79. Slip per cent.....
80. Mechanical efficiency.....
81. Capacity, gallons per 24 hours.....

THERMAL EFFICIENCY

82. Pump alone.....
83. Heater alone.....
84. Combined pump and heater.....

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Experiment No. 21

EXAMINATION OF BOILER AND SETTING

The object of this exercise is thoroughly to familiarize the student with the construction and arrangement of a boiler together with its setting and furnace.

The section will proceed to the new heating station, properly outfitted with overalls. The boiler to be examined is a Babcock and Wilcox 350 Horsepower unit fitted with Roney Mechanical Stokers. The student is advised to look up all information at hand on these types of boiler and stoker.

An internal examination of the drums will be made first. Crawl into the drum through the manhole with an extension line or lantern. Note the bumping of the head, the construction of the manhole and how it is made steam tight.

Note the location, arrangement, and construction of the dry pipe and make sketches. Notice the feed-water pipe, how it connects to the shell and where it delivers water into the boiler relative to the uptakes from the front headers. Also note any baffle plates, etc., in the drum.

Examine the surface of the drum for scale, pitting, or corrosion. Notice particularly the surface of the drum at about the ordinary water level. Make notes of any scale deposit, pitting, or corrosion.

Notice the longitudinal and circumferential riveting and how it has been caulked. Measure the pitch of the rivets and also the distances between rivet rows. Also make note of how the cross boxes for the uptakes from the headers are riveted to the drum.

Next examine the top of the boiler. Notice the location, type, size, and number of safety valves, the boiler stop valve, etc.

Examine the arrangement of the water columns and gage glasses, the method of control of the feed water, the check valves on the feed water line, etc.

The name "header" is applied to the forged steel fitting with staggered holes into which one end of the tube is rolled.

Remove one of the handhole plates from the header. Notice its construction and how it is made tight against steam pressure. Examine the way the tubes are rolled into the headers. Then examine carefully the tube roller for doing this work. Also note the construction of the turbine tube cleaners for grinding the scale off the tubes.

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Next examine the rear end and notice the form and construction of the mud drum, of the number and arrangement of the blow-off valves, etc.

Enter each side door of the setting and notice the form and construction of the fire brick baffles and the passages for gases. Estimate the cross-sectional area of each pass.

Next crawl into the furnace and note carefully every feature of its construction. Notice the arrangement and location of the steam jets under the arch. Examine the arrangement for lifting the guard and dumping the ash, the working of the grate bars, the method of feeding coal, etc.

Notice the form and construction of the ash pit.

In your report include notes on construction, description of parts, sketches or cuts of both methods of riveting drum, steam piping from boiler to steam header, showing valves, water columns and gage glass, forged steel header, bridge wall arch, dry pipe, feed water connection and blow-off connections. Describe the stokers.

Describe the function of each part and state its relation to the remainder of the boiler.

Outline how you would proceed to fill the boiler with water, put it under steam, and connect into the main steam header.

Experiment No. 22

BOILER TEST

The object of a boiler test may be to determine the efficiency of a boiler under given conditions, the comparative values of different fuels, or of different boilers working under the same condition, or the quantity of coal consumed and water evaporated in providing steam to a given engine. The method employed in making a test will vary in its details to suit the particular object in view. The general principles underlying the various methods, however, are much the same.

The unit of evaporation per lb. of steam from and at 212° F. is 970.4 B.t.u. Hence one boiler horsepower is equivalent to $970.4 \times 34.5 = 33{,}480$ B.t.u. per hour.

The student is advised to read the American Society of Mechanical Engineers' *Rules for Conducting Steam Boiler Trials*, Code of 1915.

The specific object of the proposed test should be defined and steadily kept in view.

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Measure and record the dimensions, positions, etc., of all grate surfaces, heating surface, flues and chimneys, proportion of air space to grate surface, kind of draft, natural or forced, etc.

Notice the general condition of the boiler, the flues, and the furnace. See that air leaks in the setting are closed. Clean the tubes and heating surfaces, both inside and outside.

Have an understanding regarding the kind of coal, and the condition of the coal during the test. Samples should be taken at regular intervals of all coal fired during the test, and at the end of the test these samples should be mixed and quartered, and samples taken in sealed jars for test in the calorimeter.

Establish the correctness of all apparatus used in the test for weighing and measuring. These are,

(1) Scales for weighing coal, ashes, and water.

(2) Tanks or water meters for measuring water.

(3) Thermometers and pyrometers for taking temperature of air, steam, feed water, flue gas, furnace, etc.

(4) Pressure gages, draft gages, etc.

The boiler and chimney should be thoroughly heated before the test to their usual working temperature. All boiler connections should be free from leaks. The feed water pipe should be disconnected from any other source of supply except that through the pump and measuring devices used in the test.

The blow-off pipe should be completely blanked off if possible.

The boiler test should continue for at least 10 hours though this time will vary according to the definite object of the test.

The condition of the boiler and furnace in all respects should be as nearly as possible the same at the end as at the beginning of the test. The steam pressure should be the same and the water level the same The fire upon the grates should be the same in quantity and condition, and the walls, flues, etc., should be of the same temperature. With hand-fired furnaces, it is sometimes advisable to start with a clean new fire after the boiler has been heated. In tests where the plant must be kept in commercial operation, it is usual to make a running start. The depth of fire on the grates, at the start, together with the amount of ash, color of fire, etc., should be noted, and the fire brought to the same condition at the end of the test.

In all trials the conditions should be maintained uniformly constant. The evaporation of steam and the rate of feeding coal should be kept constant. Uniformity of condition should prevail as to pressure of steam, height of water in gage glass, thickness of fire,

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the times of firing, the quantity of coal fired at one time, and the intervals between the cleaning of the fires. When such procedure is followed, it is possible to keep an accurate graphical log and to figure the test up to any chosen time. This is especially desirable when some accident may occur during the latter part of the test which makes the observations from then on, subject to error.

The quality of the steam as it leaves the boiler, should be determined by a throttling calorimeter, if it is moist, or by a thermometer if superheated.

Ashes and refuse should be weighed in a dry state. If this is not possible, weigh them in their moist condition; take an average sample of, say, 100 lb. and dry it in air until perfectly dry. Then weigh again and note the loss of weight, which loss represents the moisture content.

A sample of the flue gases should be taken at regular intervals and analyzed. This is a valuable method of determining the relative values of the different methods of firing.

Smoke observations by means of Ringelman charts should be made during the test.

Take note of every event of the test no matter how unimportant at the time, and note the time of its occurrence.

Record carefully the weights of coal and water and the time of these weighings. Note at regular intervals in the logs, the steam pressure, the draft pressure, the temperature of the boiler room, of the outside air, of the flue gases, of the calorimeter, of the steam, and of the furnace. Also record the height of the water in the gage glass.

It is also necessary to make out a heat balance which will show where the losses occur and their extent. A graphical log should be kept during the progress of the test on which the various data are plotted.

The report of test shown on the following forms is based on that recommended in the A. S. M. E. Code.

Directions for Test

Keep in mind that the results must show the relative proportion of heat in the steam to heat in the fuel. Hence the quantities and calorific values of each must determined.

Provide means for weighing coal and either weighing or measuring the feed water. If the tests are made in the University Heating Station, a platform must be constructed so that the coal can be run

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from the chute opposite the boiler to be tested, into a wheelbarrow, a sample taken, the load weighed, and wheeled and dumped into the hopper of the stoker.

Note the height of water in the gage at the beginning and the end of the test and at every hour during the test.

Provide a box into which some of the coal is thrown before each barrow is weighed. After the test quarter the contents of this box until only enough for several Mason jars remain. Seal these jars tight and take to the laboratory for calorimeter determinations and proximate analysis.

Provide thermometers to take room temperatures, feed-water temperatures, and external air temperatures, and a pyrometer to measure the flue gas temperature.

Provide draft gages for the flue pressure, also for the furnace pressure.

Provide a sampling tube for flue gas samples, some sampling bottles and an Orsat apparatus for analyzing these flue gas samples.

The steam gage on the boiler should be calibrated before and after test.

A calorimeter should be attached to the steam pipe just where it leaves the boiler to indicate the quality of the steam produced.

The ash and refuse that has dropped through the grates must be weighed at the end of the test and an average sample selected by quartering. This sample should be air dried to determine its moisture content and then analyzed for combustible.

Keep records on the accompanying logs and record test on the general form given below.

Put your description, data, and results of this test in the form of a commercial report to the owners of the boiler or boilers tested and arrange your material so that a nontechnical man can readily follow your discussion.

Plot a graphical log of the test with time as abscissae and steam pressure, draft in furnace and flue, CO_2, flue temperature, feed water temperature, total coal, and total water as ordinates.

When it is desired to calculate a heat balance for a boiler, the student is referred to Appendix No. 1 of E. A. Uehling's paper on *Combustion and Furnace Efficiencies* in Vol. 32, *Transactions A. S. M. E.*, where very complete methods of making these computations are given.

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Log of Boiler Test

Type of boiler..... Total heating surface.....
Location of boiler..... Date of test.....
Observers..... Total super heating surface.....
Size of boiler..... Weather.....

Time	Pressures						Temperatures							Water level in gage glass		
	Barometer	Steam gage	Furnace draft	Stack draft	Back pres. calorimeter		External air	Boiler room	Smoke flue	Feed water	Calorimeter	Steam	Furnace			

Log of Boiler Test

Coal and water measurements

Type of boiler..... Total heating surface.....
Location of boiler..... Date of test.....
Observers..... Kind of coal.....
Type of furnace..... Method of firing.....

Time	Coal			Water					Flue Gas			Weight of ash and refuse		
	Total weight	Tare	Net weight	Tank 1		Tank 2		Total weight	C O_2	O_2	C O			
				Time	Weight	Time	Weight							

DATA AND RESULTS OF EVAPORATIVE TEST

Code of 1915

(1) Test of.....boiler located at.....
To determine.....
Test conducted by.....

Dimensions

(2) Number and kind of boilers.....
(3) Kind of furnace.....

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(4) Grate surface (width ——— length ———)*..... sq. ft

(a) Approximate width of air openings in grate.....in.
(b) Percentage of area of air openings to grate surface.....per cent

(5) Water heating surface.....sq. ft.
(6) Superheating surface.....sq. ft.
(7) Total heating surface.....sq. ft.

(a) Ratio of water heating surface to grate surface.....(—) to 1
(b) Ratio of total heating surface to grate surface.....(—) to 1
(c) Ratio of minimum draft area to grate surface.....1 to (—)
(d) Volume of combustion space between grate and heating surface.....cu. ft.
(e) Distance from center of grate to nearest heating surface.....ft

Date, Duration, etc.

(8) Date.....
(9) Duration.....hr.
(10) Kind and size of coal.....

Average Pressures, Temperatures, etc.

(11) Steam pressure by gage.....lb. per sq. in.

(a) Barometric pressure.....in. of mercury

(12) Temperature of steam, if superheated.....deg.

(a) Normal temperature of saturated steam.....deg.

(13) Temperature of feed water entering boiler.....deg.

(a) Temperature of feed water entering economizer.....deg.
(b) Increase of temperature of water due to economizer.....deg.

(14) Temperature of escaping gases leaving boiler.....deg.

(a) Temperature of gases leaving economizer.....deg.
(b) Decrease of temperature of gases due to economizer.....deg.
(c) Temperature of furnace.....deg.

(15) Force of draft between damper and boiler.....in. of water

(a) Draft in main flue near boiler.....in. of water
(b) Draft in main flue between economizer and chimney.....in. of water
(c) Draft in furnace.....in. of water
(d) Draft or blast in ash pit.....in. of water

(16) State of weather.....

(a) Temperature of external air.....deg.
(b) Temperature of air entering ash pit**.....deg.
(c) Relative humidity of air entering ash pit.....per cent

(17) Percentage of moisture in steam or number of degrees of superheating .....per cent or deg.

(18) Factor of correction for quality of steam.....

*Unless otherwise designated this is the total area enclosed within the furnace walls projected horizontally.

** Thermometer should be protected from direct radiation of boiler and furnace.

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Total Quantities

(19) Total weight of coal as fired† ..... lb.
(20) Percentage of moisture in coal as fired ..... per cent
(21) Total weight of dry coal (Item 19 $\times \left[\frac{1 - \text{Item } 20}{100}\right]$) ..... lb.
(22) Ash, clinkers and refuse (dry)
(*A*) Withdrawn from furnace and ash pit ..... lb.
(*B*) Withdrawn from tubes, flues, and combustion chamber ..... lb.
(*C*) Blown away with gases ..... lb.
(*D*) Total ..... lb.
(*a*) Weight of clinkers contained in total ash ..... lb.
(23) Total combustible burned (Item 21 — Item 22D)** ..... lb.
(24) Percentage of ash and refuse based on dry coal ..... per cent
(25) Total weight of water fed to boiler§ ..... lb.
(26) Total water evaporated, corrected for quality of steam (Item 25 × Item 18) ..... lb.
(27) Factor of evaporation based on temperature of water entering boiler .....
(28) Total equivalent evaporation from and at 212 deg. (Item 26 × Item 27) ..... lb.

Hourly Quantities and Rates

(29) Dry coal per hour ..... lb.
(30) Dry coal per sq. ft. of grate surface per hour ..... lb.
(31) Water evaporated per hour, corrected for quality of steam ..... lb.
(32) Equivalent evaporation per hour from and at 212 deg.* ..... lb.
(33) Equivalent evaporation per hour from and at 212 deg. per sq. ft. of water heating surface* ..... lb.

Capacity

(34) Evaporation per hour from and at 212 deg. (same as Item 32) ..... lb.
(*a*) Boiler horsepower developed (Item 34 ÷ 34½) ..... bl.-h.p.
(35) Rated capacity per hour, from and at 212 deg ..... lb.
(*a*) Rated boiler horsepower ..... bl.-h.p.
(36) Percentage of rated capacity developed ..... per cent.

Economy

(37) Water fed per lb. of coal as fired (Item 25 ÷ Item 19) ..... lb.
(38) Water evaporated per lb. of dry coal (Item 26 ÷ Item 21) ..... lb.

† The term "as fired" means actual condition including moisture, corrected for estimated difference in weight of coal on the grate at beginning and end.

** If either of the two items 22*B* and 22*C* is omitted, the fact should be so stated.

§ Corrected for inequality of water level and of steam pressure at beginning and end.

* The symbol "U. E." meaning Units of Evaporation, may be substituted for the expression "Equivalent evaporation from and at 212°."

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(39) Equivalent evaporation from and at 212 deg. per lb. of coal as fired (Item 28 ÷ Item 19).....lb.
(40) Equivalent evaporation from and at 212 deg. per lb. of dry coal (Item 28 ÷ Item 21).....lb.
(41) Equivalent evaporation from and at 212 deg. per lb. of combustible (Item 28 ÷ Item 23).....lb.

Efficiency

(42) Calorific value of 1 lb. of dry coal by calorimeter*.....B.t.u.
(a) Calorific value of 1 lb. dry coal by analysis.....B.t.u.

(43) Calorific value of 1 lb. of combustible by calorimeter.....B.t.u.
(a) Calorific value of 1 lb. combustible by analysis.....B.t.u.

(44) Efficiency of boiler, furnace, and grate

$$\left[100 \times \frac{\text{Item } 40 \times 970.4}{\text{Item } 42}\right]$$ See Appendix No. 32, Code of 1915.....per cent

(45) Efficiency based on combustible

$$\left[100 \times \frac{\text{Item } 41 \times 970.4}{\text{Item } 43}\right]$$.....per cent

Cost of Evaporation

(46) Cost of coal per ton of ——— lb. delivered in boiler room.....dollars
(47) Cost of coal required for evaporating 1,000 lb. of water under observed conditions.....dollars
(48) Cost of coal required for evaporating 1,000 lb. of water from and at 212 deg.....dollars

Smoke Data

(49) Percentage of smoke as observed.....per cent
(a) Weight of soot per hour obtained from smoke meter.....per cent

Firing Data

(50) Kind of firing, whether spreading, alternate, or coking.....
(a) Average thickness of fire.....in.
(b) Average intervals between firings for each furnace during time when fires are in normal condition.....min.
(c) Average interval between times of leveling or breaking up.....min.

(51) Analysis of dry gases by volume
(a) Carbon dioxide (CO_2).....per cent
(b) Oxygen (O).....per cent
(c) Carbon monoxide (CO_2).....per cent
(d) Hydrogen and hydrocarbons.....per cent
(e) Nitrogen, by difference (N).....per cent

*If the calorific value is desired per lb. of coal "as fired," multiply Item 42 by $\frac{100 - \text{Item } 20}{100}$

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(52) Proximate analysis of coal

		As fired	Dry coal	Combustible
(*a*)	Moisture	.....	.....	.....
(*b*)	Volatile matter	.....	.....	.....
(*c*)	Fixed carbon	.....	.....	.....
(*d*)	Ash	.....	.....	.....
		100 per cent	100 per cent	100 per cent

(*e*) Sulphur, separately determined referred to dry coal.....per cent

(53) Ultimate analysis of dry coal

(*a*) Carbon (C).....per cent
(*b*) Hydrogen (H).....per cent
(*c*) Oxygen (O).....per cent
(*d*) Nitrogen (N).....per cent
(*e*) Sulphur (S).....per cent
(*f*) Ash.....per cent

100 per cent

(54) Analysis of ash and refuse, etc.

(*a*) Volatile matter.....per cent
(*b*) Carbon.....per cent
(*c*) Earthy matter.....per cent

100 per cent

(*d*) Sulphur, separately determined.....per cent
(*e*) Fusing temperature of ash.....deg.

(55) Heat balance, based on dry coal

		Dry coal	
		B.t.u.	Per cent
(*a*)	Heat absorbed by the boiler (Item 40 × 970.4)		
(*b*)	Loss due to evaporation of moisture in coal		
(*c*)	Loss due to heat carried away by steam formed by the burning of hydrogen		
(*d*)	Loss due to heat carried away in the dry flue gases		
(*e*)	Loss due to carbon monoxide		
(*f*)	Loss due to combustible in ash and refuse		
(*g*)	Loss due to heating moisture in air		
(*h*)	Loss due to unconsumed hydrogen and hydrocarbons, to radiation, and unaccounted for		
(*i*)	Total calorific value of 1 lb. of dry coal (Item 42.)		100

If it is desired that the heat balance be based on coal "as fired" or on "combustible burned" the items in the first column are multiplied by the proportion $\frac{100 - \text{Item } 20}{100}$ for coal "as fired" or by the proportion $\frac{100 - \text{Item } 20}{100 - (\text{Item } 20 + \text{Item } 24)}$ for "combustible burned."

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EXPERIMENT NO. 23

TEST OF VERTICAL BOILER AND ENGINE

This experiment is arranged to show the performance of a combined vertical boiler and engine equipment, under constant loading. Although elementary in character, yet it embodies the elements of a test of a large steam power plant, and it is intended to give the student practice which will fit him to undertake the more elaborate tests.

The alternate methods of starting and stopping a test will be used. It consists of the following procedure:

A preliminary run is made in order thoroughly to heat the boiler and engine; then, the fire and ash pit are cleaned. The amount of coke left on the grate is estimated as nearly as possible, steam pressure recorded, and the water level marked for the boiler. The load on the engine is recorded with the engine running under the control of the governor. Before the end of the test, the fire should be burning just as at the beginning, and the fire cleaned in such a manner as to leave a bed of coke on the grates of the same depth as at the start. The steam pressure, the water level and brake load, are brought as nearly as possible to the same place as at the start.

It will be found that it requires some skill and constant attention to keep an even fire, and maintain a constant steam pressure and water level. If during the test the fire is burning low, feed as little water to the boiler as possible until the steam pressure is restored. When the fire is burning briskly, more water than is actually needed may be supplied and thus prevent loss of steam through the safety valve. The injector should be kept running continuously as nearly as possible.

Directions.—After building a fire and steam pressure has been raised, run the preliminary test with the brake load as assigned by the instructor. Have the instructor inspect the log sheet.

Clean fire and ash pit and note depth of the coal bed. The fire develops the most heat when the coke is spread evenly over the grate at a depth level with the door.

Record the time of starting the regular test, steam pressure, water level, brake load, weight of coke used, and condition of the feed water tanks. At the beginning of the test the water level should be at about two-thirds the height of the glass, measured and marked

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with a string. Maintain 90 pounds per square inch steam pressure throughout the test. Maintain test conditions as long as the time will permit.

Close the test by noting the same items as in the starting.

The coke as fired is assumed to have a heating value of 13,000 B. t. u. per pound and to contain 8 per cent moisture.

Report.—Follow the standard form for the reporting of this experiment.

In describing the plant, describe the boiler in the same manner as has been suggested for the engine in preceding experiments, mentioning the draft, etc.

Tabulate similarly to previous forms, the following average results under "Data and Results." Read Experiment No. 22.

Measure up the boiler and determine sq. ft. of grate surface and sq. ft. of heating surface.

Cylinder diameter 6½ in., stroke 8 in., piston rod 1⅛ in. diameter.

PRINCIPAL DATA AND RESULTS OF BOILER TEST

1. Grate surface (width ——— length ———) ..... sq. ft.
2. Total heating surface ..... sq. ft.
3. Date .....
4. Duration ..... hr.
5. Kind and size of coal .....
6. Barometric pressure ..... in. of mercury
   (a) ..... lb. per sq. in. abs.
7. Steam pressure by gage ..... lb. per sq. in.
   (a) absolute ..... lb. per sq. in.
8. Temperature of feed water entering boiler ..... deg.
9. Percentage of moisture in steam or number of degrees of superheating ..... per cent or deg.
10. Percentage of moisture in coal ..... per cent
11. Coal per hour ..... lb.
12. Dry coal per hour ..... lb.
13. Dry coal per sq. ft. of grate surface per hour ..... lb.
    (a) Ash and refuse ..... lb.
14. Factor of evaporation .....
15. Water evaporated per hr ..... lb.
16. Equivalent evaporation per hour from and at 212 deg ..... lb.
17. Equivalent evaporation per hour from and at 212 deg. per sq. ft. of heating surface ..... lb.
18. Boiler horsepower developed .....
19. Rated capacity per hour, from and at 212 deg ..... lb.
20. Percentage of rated capacity developed ..... per cent
21. Equivalent evaporation from and at 212 deg. per lb. of dry coal ..... lb.

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2. Equivalent evaporation from and at 212 deg. per lb. of combustible .....lb.
3. Calorific value of 1 lb. of dry coal by calorimeter.....B.t.u.
4. Calorific value of 1 lb. of combustible by calorimeter.....B.t.u.
5. Efficiency of boiler, furnace, and grate.....per cent
6. Efficiency based on combustible.....per cent

Results from Engine

7. Revolutions per minute.....
8. Brake load.....lb.
9. Mean effective pressure h.e. lbs per sq. in.....(m.e.p.)
0. Mean effective pressure c.e lbs. per sq. in.....(m.e.p.)
1. Indicated horsepower, h.e.....(i.h.p.)
2. Indicated horsepower, c.e.....(i.h.p.)
3. Total indicated horsepower .....(i.h.p.)
4. Brake horsepower.....(br. h.p.)
5. Friction horsepower.....(f.h.p.)
6. Mechanical efficiency.....per cent
7. Steam used per indicated horsepower hour.....(i.h.p.) lb.
8. Heat supplied per indicated horsepower hour.....B.t.u.
9. Heat equivalent to the i.h.p.h.....B.t.u.
10. Thermal efficiency in per cent, based upon the i.h.p.....per cent

Results from the Plant

11. Coke used per indicated horsepower hour.....(i.h.p.h.) lbs.
12. Coke used per brake horsepower hour.....(br. h.p.h.) lbs.
13. Cost of power per brake horsepower hour if coke costs $7.70 per ton.....(br.h.p.h.)
14. Thermal efficiency of plant.....per cent

Experiment No. 24

TEST OF A SUPERHEATER

The Foster superheater in the laboratory consists of three sets of 4-pipe return bend elements. Each element is made up of a 2 in. seamless drawn boiler tube bent in U shape. The straight legs of these tubes are fitted on the outside with a series of cast iron rings or flanges placed close to each other and practically forming part of the tube. The exposed heat absorbing surface is thus of cast iron, which is best adapted to withstand the action of the heated gases. The cast iron rings provide a very large surface of exposure to heat. The upper end of the tube is protected by a cast iron casing bolted in place.

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Inside these elements other 1 in. tubes of wrought iron are placed. These tubes are closed at their ends and are centrally supported by means of knobs or buttons throughout their length. Hence there is formed a thin annular space between the inner and outer tubes through which the steam passes. It is thus quickly heated up in the most efficient manner.

The ends of the elements are expanded into the forged steel drums from which the steam enters and leaves or into small return headers between the sets of elements. The hand holes opposite the ends of the elements are closed by steel plugs with copper gaskets.

The straight length of the elements is 4 ft. 3½ in. long, so that the net inside steam heating surface is 48.8 sq. ft.

The grate, which can burn either coal or coke, is 23 in. x 24 in. in size. The flue gases pass through a 10 in. x 10 in. duct and out into a chimney in the side of the building.

The steam passes counter-current through the superheater,—that is, the coolest steam is exposed to the coolest gases and vice versa.

When it is desired to put the superheater in operation, start the fire and open the valve on the inlet steam line very slowly. Build the fire up slowly, allowing any condensation to flow out through the drains. When the superheater is free from moisture, open the valve on the outlet steam line and gradually establish circulation through the superheater.

After the steam is circulating, watch the thermometer on the outlet closely and control the fire so as to increase the temperature at a slow rate. When the desired temperature has been obtained, the fire should be controlled by the damper. Great care must be taken not to exceed the limiting temperature of the superheater, which is 550° F.

The superheater is capable of superheating 2,000 lbs. of steam per hour at 120 lb. gage pressure to a final temperature of 550° F.

When the test on the superheater is completed, the fire should be drawn at once. The load on the engine must be left constant and the engine must be kept in operation until the temperature of the steam at outlet is that of dry saturated steam. The hot tubes and setting are thus cooled down so that no undue heating will take place in any portion. To shut down a superheater under high temperature is sure to start some joints leaking the next time it is fired up. It is very important that great care be exercised in shutting down the superheater.

A separately fired superheater can be tested in much the same way as a boiler. The steam through the superheater should be passed

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into a surface condenser and weighed. The quality and pressure of the inlet steam and the temperature and pressure of the outlet steam must be determined. The weight of fuel, weight of ash and refuse, flue gas temperatures, drafts, etc., would be measured as in a boiler test.

When a superheater is built into a boiler, it is usually considered a part of the boiler plant and is tested as a combined unit of boiler and superheater.

One of the most important determinations in a superheater test is the measurement of the temperature of the outlet steam. High grade mercurial thermometers are used up to 700° F., but the accuracy of these thermometers is not always constant. Platinum resistance thermometers enclosed in a suitable metal sheath give the best service. Thermocouples may also be used to advantage.

Directions for Test

Fire up superheater, turn on steam, and start engine according to preceding instructions. Condense the steam passing through the engine or turbine and thus measure the amount of steam passing through the superheater.

Make an ..... hour test, taking the observations noted above and recording data in the following forms.

In your final report work up your data on the following result form.

Comment on your results and compare the operation of a superheater with that of a boiler.

Log of Superheater Test

TEMPERATURES AND PRESSURES

Type of superheater..... Total heating surface.....
Location of superheater..... Capacity.....
Limiting temperature..... Date of test.....
Weather..... Observers.....

Time	Pressures						Temperatures							
	Barometer	Steam inlet	Steam outlet	Stack draft	Furnace draft	Calorimeter	External air	Fire room	Smoke flue	Calorimeter	Steam outlet	Furnace	Wet bulb	Dry bulb

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Log of Superheater Test

Coal, Ash, and Water Measurements

Type of superheater..... Located at.....
Date of test..... Observers.....

Time	Coal			Flue Gas			Weight of ash and refuse	Total weight of condensed steam
	Total weight	Tare	Net weight	C O_2	O_2	C O		

Report of Superheater Test

General Dimensions of Superheater

1. Number of elements.....
2. Diameter tubes internal, in.....
3. Diameter tubes external, in.....
4. Length of element.....
5. Inside heating surface, sq. ft.....
6. Kind of furnace.....
7. Dimensions of grate.....
8. Ratio of grate area to inside heating area.....
9. Area of flue opening, sq. ft.....
10. Floor space of superheater, sq. ft.....

Conditions

11. Date of trial.....
12. State of weather.....
13. Duration of trial, hr.....
14. Humidity.....
15. Kind of fuel.....

Average Pressures

16. Barometer.....
17. Steam pressure gage, entering superheater, pounds.....
18. Steam pressure gage, leaving superheater, pounds.....
19. Force of draft over fire, in. water.....
20. Force of draft leaving superheater, in. water.....

Average Temperatures

21. External air, degrees F.....
22. Fire rooms, degrees F.....
23. Flue gases, degrees F.....
24. Steam leaving superheater, degrees F.....

Fuel

25. Kind of firing.....
26. Thickness of fire, in.....
27. Total coal as fired, lb.....
28. Total dry coal, lb.....
29. Total dry ash and refuse, lb.....
30. Per cent refuse of coal as fired.....
31. Calorific value per lb. of dry coal B.t.u.....

Proximate Analysis of Coal in Per Cent

32. Moisture.....
33. Volatile matter.....
34. Fixed carbon.....
35. Ash.....

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ANALYSIS OF REFUSE IN PER CENT

36. Combustible.....
37. Ash.....

STEAM

38. Quality of steam entering superheater.....
39. Weight of wet steam entering superheater, lb.....
40. Weight of dry steam entering superheater per hr.....

ECONOMIC RESULTS

41. Pounds steam dried and superheated per lb. of dry coal.....
42. B.t.u. taken up by steam per lb., dry coal.....
43. Heat transmitted per sq. ft. of heating surface per hour.....
44. Efficiency of superheater, per cent

$$= \frac{\text{B.t.u. taken up by steam per lb. of dry coal}}{\text{Calorific value of 1 lb. of dry coal}}$$

FLUE GAS ANALYSIS

45. Carbon dioxide, by volume.....
46. Oxygen.....
47. Carbon monoxide.....
48. Nitrogen.....

HEAT BALANCE PER POUND OF COAL

49. Loss due to evaporating moisture in coal.....
50. Loss in flue gases.....
51. Loss due to incomplete combustion.....
52. Loss in ash and refuse.....
53. Heat used in superheating.....
54. Loss due to radiation.....

EXPERIMENT NO. 25

MEASUREMENT OF MASS

THE BALANCE

The balance is one of the most accurate scientific instruments available, and for that reason should be used with care. The ordinary analytical form has a total capacity of about 150 grams and will weigh this amount to an accuracy of about $\frac{1}{10}$ of a milligram.

The balance as shown in Fig. 13 consists essentially of a beam (E) which is capable of swinging about its center upon a knife-edge (K) which rests upon an agate plate. At equal distances from the knife-edge, at (0), and (0′), the pans (A) and (B) are supported by means of agate plates and knife-edges.

By means of the milled head (M) the supports (D, D′) and (C, C′) the beam and pans, respectively, are raised off the agate bearings to keep the edges sharp. The arrestment (M) should always be brought up when the balance is not in use, or when placing masses on either pan, or changing weights.

A pointer (P) is attached to the beam (E), and swings in front of the scale (S) so that fine adjustments can be made. To avoid negative readings the center of the scale is counted as 10. A graduated scale giving milligrams and fractions thereof is attached to the beam

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and a small rider (F) placed thereon by the rod (G). This rider avoids the inconvenience of handling small weights on the pans. Usually the rider is marked with zero at the center and 10 at the support of the pan. Each division is then one milligram and the total capacity of the rider scale ten milligrams.

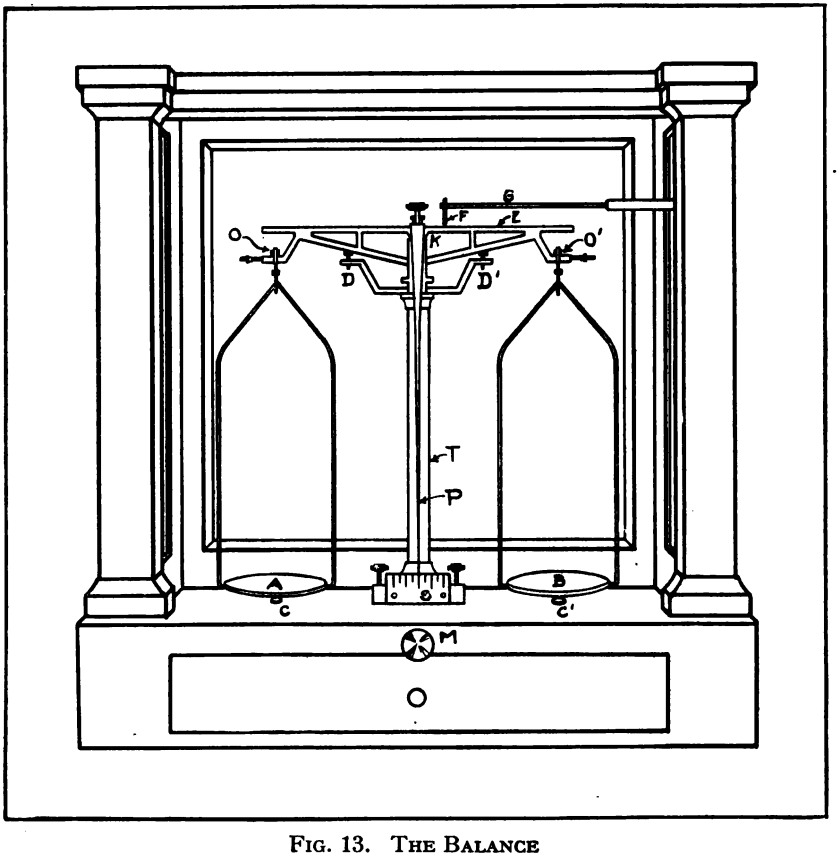

FIG. 13. THE BALANCE

THE WEIGHTS

A set of weights usually consists of brass gram weights, with platinum or aluminum fractional weights. The brass weights have their value in grams stamped on them. The fractional weights are stamped either in fractions of a gram or as so many milligrams, a milligram being $\frac{1}{1000}$ of a gram. The set of fractional weights usually consists of:

One 500 mg	Two 100 mg	One 20 mg
One 200 mg	One 50 mg	Two 10 mg

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Each set of weights is capable of measuring the mass of a capacity equal to the sum of the weights in the set. Mixing of weights of different sets is inexcusable and a great inconvenience. Much time is saved if the weights are kept in a systematic order.

Use of Balance

The following rules and suggestions should be followed to obtain good results and to maintain the balance in good order:

1. Determine the zero point before each weighing.
2. Do not stop the swings with a jerk as this will disturb the zero reading. This can be avoided by raising the arrestment when the pointer is passing the center of the scale (S).
3. Always handle all weights with pincers and never with the fingers.
4. The arrestment should never be completely lowered when the equilibrium is not perfect enough to prevent the pointer from swinging more than five divisions from the center of the scale. A very slight lowering will be sufficient to determine this.
5. Raise the arrestment whenever weights are to be added or removed.
6. Place the object to be weighed in the center of the left scale pan and the weights in the center of the right pan, adding the smaller weights in the order of their size.
7. When making adjustments with the rider close the balance case to prevent air currents and seat yourself in front of the zero position of the pointer. The swings should not be more than 5 to 7 divisions to either side of the center.
8. Substances liable to injure the pans should be weighed in a watch-glass, beaker, or stoppered bottle.
9. When the weighing is finished, raise the arrestment, replace the weights in the box in their respective places, and close the case. Never leave weights on the pan. The rider should be placed at the zero point.

TO PERFORM A WEIGHING

(a) *To determine the zero of the balance.* Since it is time consuming to wait for the pointer to come to rest, the position of equilibrium is best determined by the method of swings. As the length of the swing is gradually growing less, the average of the first and third

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swing will be as far to one side of zero as the second swing was to the other side, hence the average of the swings to both sides will be the zero point. To avoid negative readings the center of the pointer scale will be called 10, and the extreme left will be called 0.

Example:	—Readings—	
	Left	Right
	9.2	12.4
	8.4	
Aver.	8.8	12.4
	Zero 10.6	

(b) *Weighing.* Place the object to be weighed in the left scale pan and place weights in the other side until the beam moves but little to either side. Now make the final adjustments with the rider, keeping the case closed. It is a real economy of time to compute the fractions of a milligram instead of determining the same on the balance. This may be done by noting how many divisions the pointer on the scale is moved by a change of one milligram on the rider beam. The fraction of a milligram to be added to the weight is given by

$$\frac{a-c}{a-b} \text{ where}$$

(a) = position of rest of pointer for the smaller weight.
(b) = position of rest of pointer for a weight one milligram larger.
(c) = position of rest of pointer for the zero point.

Suppose that with a weight on the right pan of 23.522 grams the pointer comes to rest on the right side of the center, and that with a weight of 23.523 grams the position of rest is on the left side of centre.

Example:	Readings		
	Left	Right	Zero
	4.0		
Balance unloaded	4.5	14	9.12 = c
Balance with 23.522 grams	8.5	16.5	
		15.5	12.25 = a
Balance with 23.523 grams	2.0		
	2.8	15	8.7 = b

$$\frac{a-c}{a-b} = \frac{12.25-9.12}{12.25-8.7} = 0.88 \text{ milligrams to be added}$$

Hence the weight is 23.5229 grams.

According to the above outlined methods determine the weight of the object given you by the instructor.

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COAL ANALYSIS

Sampling

Equal in importance to the accurate performance of an analysis, is the choice of the sample from a lot of coal. If the sample is not truly *representative*, the analysis counts for naught. In taking a sample from cars, wagons, pile, or bunkers, portions of coal should be taken from below the surface and from all parts of the lot. From inspection of the kind of coal, proportionate amounts should be taken of the large and small sizes as well as the fine dust. About 200 pounds of any lot is sufficient to prepare for sampling.

The lot of 200 lb. is broken on a clean floor, by any suitable means to a size of about ½ in. diameter, thoroughly mixed, and spread out in a flat circular pile. The mass is quartered, and opposite quarters discarded. The remainder is mixed again, made into a flat pile, and quartered, throwing out the opposite quarters. The remaining portion is now further disintegrated to about a size ¼ in. in diameter, and the quartering, mixing, and discarding continued until the remainder amounts to about a quart. This portion is put into a glass fruit jar, or a covered tin can and the cover securely sealed on. It is important that this be done to avoid any deterioration of the sample before reaching the laboratory for test.

Upon arrival at the laboratory the coal is emptied out of the can or jar and disintegrated as quickly as possible to a fineness of about a 20-mesh sieve. The ground coal is thoroughly mixed and a small portion, about 50 grams, put into a tightly stoppered bottle. This is the sample used for analysis. The larger portion is put away for future use in case of a check.

Analysis

The proximate analysis is the one which is usually made on coal, because it gives the coal user all the information necessary for combustion purposes. This analysis consists in determining the moisture, volatile matter, fixed carbon, and ash in coal, and is essentially an empirical analysis. The method of analysis about to be described is the one prescribed by the Committee on Coal Analysis of the American Chemical Society, and is in common use throughout this country. In this analysis, the moisture and ash determinations are perhaps of greatest importance and most accurately determined. These substances are also of great significance because they are positive detriments to the coal, being noncombustibles. In addition

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the ash may give much trouble in the form of clinkers, and is also costly to handle and dispose of.

A determination of sulphur is sometimes made, especially when the coal is desired for gas making, blacksmithing, or metallurgical purposes. For methods of determining sulphur the student is referred to any good text on quantitative analysis.

Experiment No. 26

PROXIMATE ANALYSIS OF COAL

Read over the foregoing article on "Coal Sampling" in connection with this experiment.

(a) *Moisture.*—Into a covered crucible weigh about four grams of coal prepared for analysis. This should be done as quickly as possible to avoid a loss of moisture. Remove the cover and heat at 105 to 110 degrees Centigrade for one hour in an oven whose temperature can be controlled within these limits. At the end of the hour of heating place the crucible with its cover and charge of coal into a dessicator to cool, and weigh after cooling at least twenty minutes. The loss in weight is the free moisture in the coal.

(b) *Volatile Matter.*—Weigh one gram of the coal prepared for analysis into a crucible supplied with a snugly fitting cover. Support the covered crucible on a metal triangle which should be at least 8 to 10 centimeters above the top of the burner. Heat the covered crucible for 7 minutes in the full flame which should be at least 20 centimeters high. Cool the crucible in a dessicator for about twenty minutes and then weigh. The loss in weight is due to the loss of moisture plus volatile matter.

The room in which the test is made should be free from drafts to prevent a variation in the intensity of the flame playing on the crucible.

(c) *Ash.*—The crucible and residue from the preceding test are now heated over a free flame until the carbon has all burned off and the weight of the crucible and contents is constant. The contents of the crucible should be stirred carefully with a platinum wire to break up the ash which is a powdery mass when all the carbon is burned off. It is a great help to remove the cover in this test, and to incline the crucible so as to admit air for oxidation. Any tarry deposit on the cover should also be burned off. Cool in a dessicator as before and weigh. The remainder in the crucible is the ash.

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(d) *Fixed Carbon.*—This quantity is determined by difference. Subtract from 100 per cent the sum of the percentages of moisture, volatile matter, and ash, and the difference is the percentage of fixed carbon.

(e) *Modifications.*—The fuel testing division of the U. S. Geological Survey in *Bulletin No. 323* points out that the official method is open to some objections. It appears that with very wet coals, those high in volatile matter, such as peat, and coals finely ground, there is such a rapid evolution of gas that particles of coal are mechanically expelled with the gases. It is recommended that for the volatile matter test the covered crucible be heated for four minutes with a very small flame and then for seven minutes additional with the full flame 20 centimeters high.

Include in your report an outline of the method of conducting the experiment. Tabulate your data and computations neatly. Keep a copy of your results for use in experiment No. 34. Calculate the heating value of the coal, using the proximate curves on page 00.

Experiment No. 27

HEATING VALUE OF COAL

a. *Principles.*—In most calorimeters the substance under test is burned with an excess of oxygen in a closed container immersed in a known quantity of water. The heat resulting from the combustion of the fuel is given over to the container and the water, and the rise in temperature of the water is measured by a sensitive thermometer. The heat of the combustion of the fuel is then the heat given over to the water and container. The container being usually of metal of various kinds and some other substances, contains a certain amount of heat. This capacity for taking up heat is commonly expressed in its equivalent of water, i. e., the metal of the container and accessories has a definite "water equivalent."

The heating value of the fuel if desired in British Thermal Units, B.t.u. per pound is given by the following expression:

$$\text{B.t.u. per lb.} = \frac{(W+k)\ (t \times 1.8)}{G}$$

where W = weight of water used in grams.
k = water equivalent in grams.
G = weight of fuel used in grams.
t = corrected rise in temperature in Centigrade degrees.

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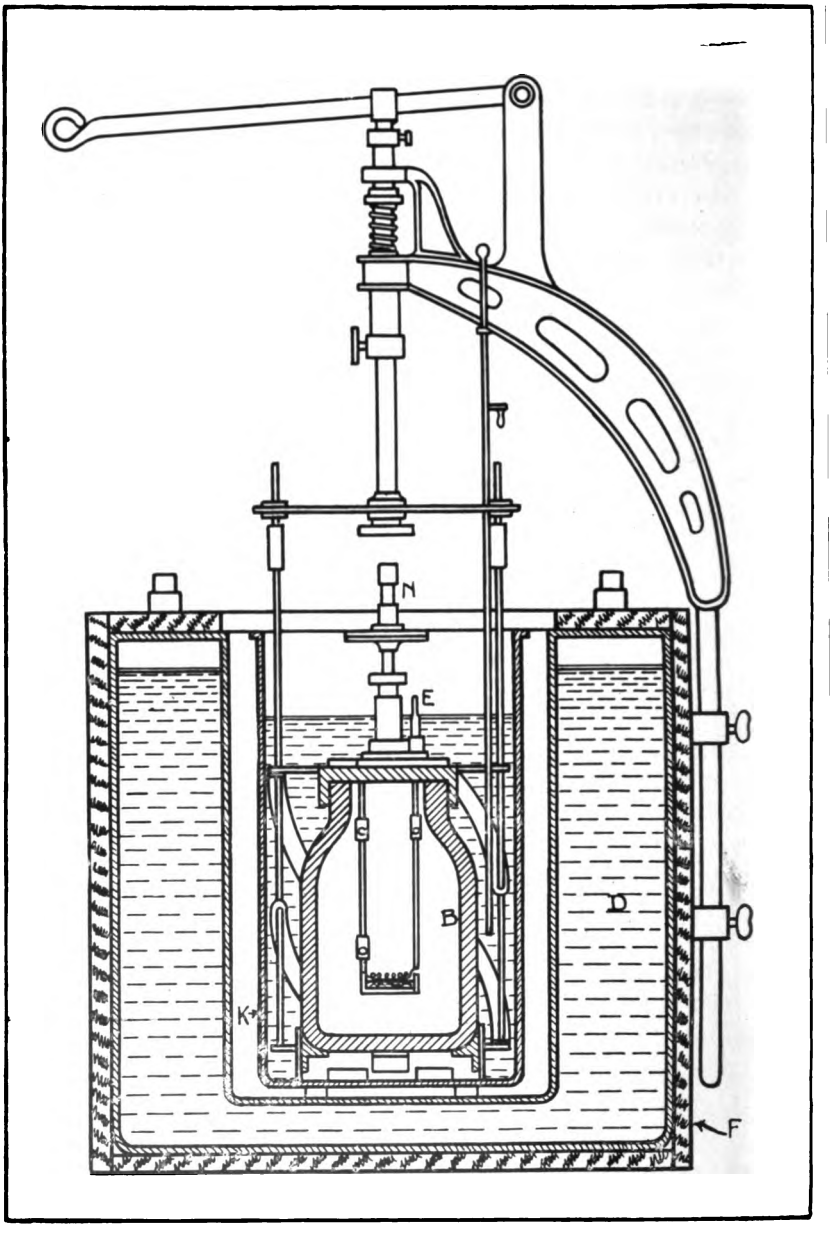

FIG. 14. MAHLER CALORIMETER

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There are several types of calorimeters, (1) those operating at constant pressure, and (2) those operating at constant volume. The constant volume form is in most common use, of which the bomb is an example. Another constant volume calorimeter is the sodium peroxide fusion type, of which the Parr is an example. It is quite generally recognized that the bomb calorimeter is the most reliable form, and of these the Mahler, Emerson, and Kroeker are good examples.

(b). *Description of Mahler Calorimeter.*—The Mahler apparatus is shown in Fig. 14 and Fig. 15. The bomb itself is shown in Fig. 15

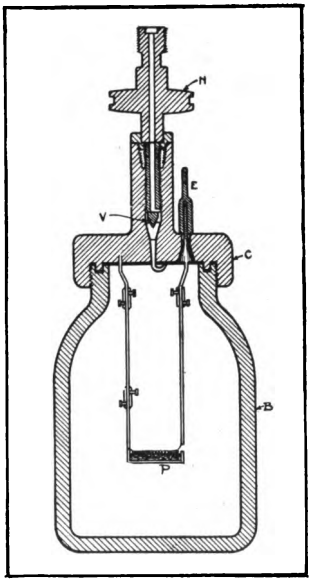

FIG. 15. MAHLER BOMB

and consists of a steel cylinder (B) with a screw cap (C), the insides of which are lined with porcelain. The pan and supports for holding the fuel are shown at (P) and are made of platinum. The calorimeter consists of a water-jacketed container (D) covered with felt (F). Inside of this there is a brass pail (K) into which the bomb (B) and the water measured are placed, together with the stirrer and thermometer. The water in the calorimeter (D) should be at about room temperature, and there should be no water on the inside of the calorimeter chamber nor on the outside of the brass pail (K). The thermometer should be one graduated to 1/100 degree Centigrade. A so-called Beckman thermometer will do nicely.

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(c). *Preparation of Bomb.*—Insert the screw valve (N) into the cap (C) and then support the cap on a ring stand. Place the pan and supports in position and connect the two supports with a fine iron wire. Place into the pan a known weight of material to be burned. If this is coal, take about one gram. It is best to weigh the coal in a small test tube and determine the amount used from the weight of the tube with and without coal.

Bituminous coal should be ground to 100 mesh, and cokes and anthracites to a very fine powder.

Place the bomb in the vise and screw on the cover tightly, being careful to avoid burring the nut with the big wrench.

In the brass pail weigh out 2,400 grams of water which is slightly above room temperature, and place this in the calorimeter.

To fill the bomb with oxygen proceed as follows:

See that the valve (N) is open about 1½ turns, connect the bomb to the copper pipe leading from the oxygen tank. These tanks when freshly filled are under a pressure of 90 atmospheres, so use *caution!* First open the tank valve carefully to about ¼ turn, then open valve at the gage and allow the bomb to fill slowly to avoid blowing material out of the pan. Allow the pressure to rise to 18 atmospheres. To test for leaks it is desirable, when filling the bomb, to have the same stand in a jar of water which rises up over the cover of the bomb. If there are any leaks, the cap can be tightened. When the bomb is filled with oxygen, (1) close the tank valve, (2) close the gage valve, (3) close (N) on the bomb. The valve (V) on (N) is a cone seated valve and is a nice piece of workmanship, so use caution and do not screw down (N) too hard. It should be opened easily. To close (N) it is best to lift the bomb at (N) and turn the bomb, holding (N) stationary. Remove the bomb from the copper pipe.

Place the bomb in its ring and set centrally into the brass pail in the calorimeter. Put the stirrer in position and adjust it so that it moves freely between the bomb and the pail. The ignition wires are now placed at (N) and (E). Insert the Beckman thermometer. Test current before putting calorimeter together by burning a piece of ignition wire in the atmosphere.

(d). *Combustion Observations.*—With apparatus all in place run the stirrer briskly and continuously to the close of the test. Take observations to the nearest 0.001 degree every minute for five minutes, at the end of the fifth minute ignite. Pull the switch open as soon as the lights go out. Take readings every half minute until the temperature passes the maximum, then continue the observations each minute for about ten minutes longer.

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This completes the observations. Remove (1) the thermometer, (2) ignition wires, (3) disconnect the stirrer from the moving device, and (4) lift the pail with the bomb and stirrer out of the calorimeter. Now take the bomb out of the water and *first* release the pressure by opening (N). Unscrew the cap and observe whether combustion has been complete. Wash out the bomb and cover and dry with a towel. Take (N) out of the cap and by means of filter paper dry out the valve seat at (V).

(e). *Cooling Correction.*—During the performance of the test heat may be given off to the surroundings from the calorimeter or taken in by the calorimeter. This condition will affect the difference between the initial and the observed maximum on the thermometer. Usually heat is given by the calorimeter to the surroundings and a "cooling correction" must be made. This correction is added to the difference between the observed initial and maximum temperatures. There are several ways of making this correction. The scientifically accurate way is to use Pfaundler's formula (*Ann. der Phys. and Chem.* 11, 207):

$$C = nv + \frac{v' - v}{t' - t}\left[\Sigma_{n-1}^{1}\,\theta + \frac{\theta_o + \theta_n}{2} - nt\right]$$

C = the correction to be added to the observed maximum
n = number of half minute intervals from the instant of ignition to the instant of maximum temperature
v = change in temperature per half minute before ignition
v′ = change in temperature per half minute after combustion is complete
t = average temperature before ignition
t′ = average temperature after combustion is complete
θ_o = temperature at the instant of ignition
θ_n = temperature at instant of complete combustion
$\Sigma_{n-1}^{1}\,\theta$ = summation of the temperatures from the instant of ignition to complete combustion

A simpler, though not scientific method, has been suggested by Mr. E. H. Peabody, (Stevens Indicator 1908) which gives approximate results that may be sufficient for many commercial purposes. This method does very well where the maximum temperature is reached within about four half minute intervals after the instant of ignition. The formula is as follows:

$$C = x + (n-1)\,y$$

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C = correction to be applied
x = change in temperature per half minute before ignition
y = change in temperature per half minute after combustion is complete
n = number of half minute intervals from the instant of ignition to the instant of maximum temperature

Add the correction to the observed maximum, and from the sum subtract the temperature just before ignition; the difference is the corrected rise. The values of (x) and (y) are positive when the temperature is falling, and negative when it rises.

(f). *Water Equivalent.*—The water equivalent is best determined by burning a substance of known heating value in the calorimeter, such as pure benzoic acid or naphthaline. Benzoic acid has a calorific value of 6,320 calories per gram and naphthaline has 9,692 calories per gram. The amount used should be such that the rise in temperature is equal to the rise for coal used. In the equation

$$\text{Calories per gram} = \frac{(W+k)\,t}{G}$$

the only unknown is the value of (k) if the test has been carried out in the manner already described, and this can be easily computed.

(g). *Volalite Liquids.*—A volatile liquid like gasoline or alcohol can not be weighed out like coal. Into a thin glass or gelatine capsule weigh a portion of the liquid, about 0.3 to 0.4 gram and proceed as described. If a gelatine capsule is used, a blank must be run and the heating value of the capsule subtracted from the sum of capsule and liquid.

(h). *Heating Value of Coal Computed from Analysis.*—A calorimeter is not always available for the determination of the heating value and it is sometimes desirable to know the same to within a few per cent. Such approximation may be made from the proximate analysis in various ways.

One method is an adaptation of Goutal's formula as described in the *Wisconsin Engineer*, December, 1911, where the formula is given

B.t.u. per pound as received = $14760C + aV$

where

C = fixed carbon as a decimal of coal as received
V = volatile matter as a decimal of coal as received
a = a constant. The curve in Fig. 16 shows the various values of (a) corresponding to values of (V).

The method will give results that will average about two per cent of the correct value.

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Another method is the one proposed by Mr. Alfred Lotz of the Underfeed Stoker Company as shown by the curve in Fig. 17 which is here printed by their permission.

In your report use Peabody's formula for determining the correction factor C.

Give a general description of method of conducting experiment, tabulate your data and sample computations neatly.

Use the same kind of coal in this experiment as in the Proximate Analysis of coal and compare the results of both experiments. Compute B.t.u. per lb. of coal as used in bomb calorimeter, B.t.u. per lb. of dry coal and B.t.u. per lb. of combustible.

EXPERIMENT NO. 28

HEATING VALUE OF GAS IN A JUNKER'S CALORIMETER

a. *Description of Calorimeter.*—The Junker's calorimeter for gas is one of the oldest in use and is a very satisfactory means of determining the heating value, when properly used. The complete outfit is shown in Fig. 18, while in Fig. 19 the calorimeter is shown in section. Referring to Fig. 19 it will be seen that the calorimeter is made of thin copper and consists of a combustion chamber (2) surrounded by passages for water. The products of combustion from the burner (3) pass up into the chamber and down a set of concentric flues into an annular space (4) and out of the calorimeter at (5). The water flows in the opposite direction to the gas. The water enters at (6), passes a screen to catch dirt, and fills a cup (7), from which the overflow passes out at (8). From the cup (7) the water passes down through the valve (9) and past the thermometer and into the calorimeter body at (10). From here it flows upwards surrounding the tubes and passes the baffle plates (11) and the thermometer (12), thence into a weir overflow (13) and to the waste pipe or bucket. It is thus seen that there is a constant head of water on the calorimeter equal to the difference in level of the two weirs. Water should always flow out of the upper overflow at (8) so that no air enters with the water.

The pressure regulator (R) is for the purpose of keeping an even pressure on the burner, to insure a uniform rate of combustion, and to avoid the pulsating effect from the meter (M).

The meter (M) is of the wet type and is usually graduated to read $\frac{1}{10}$ cubic foot per revolution of the big hand. The large dial is

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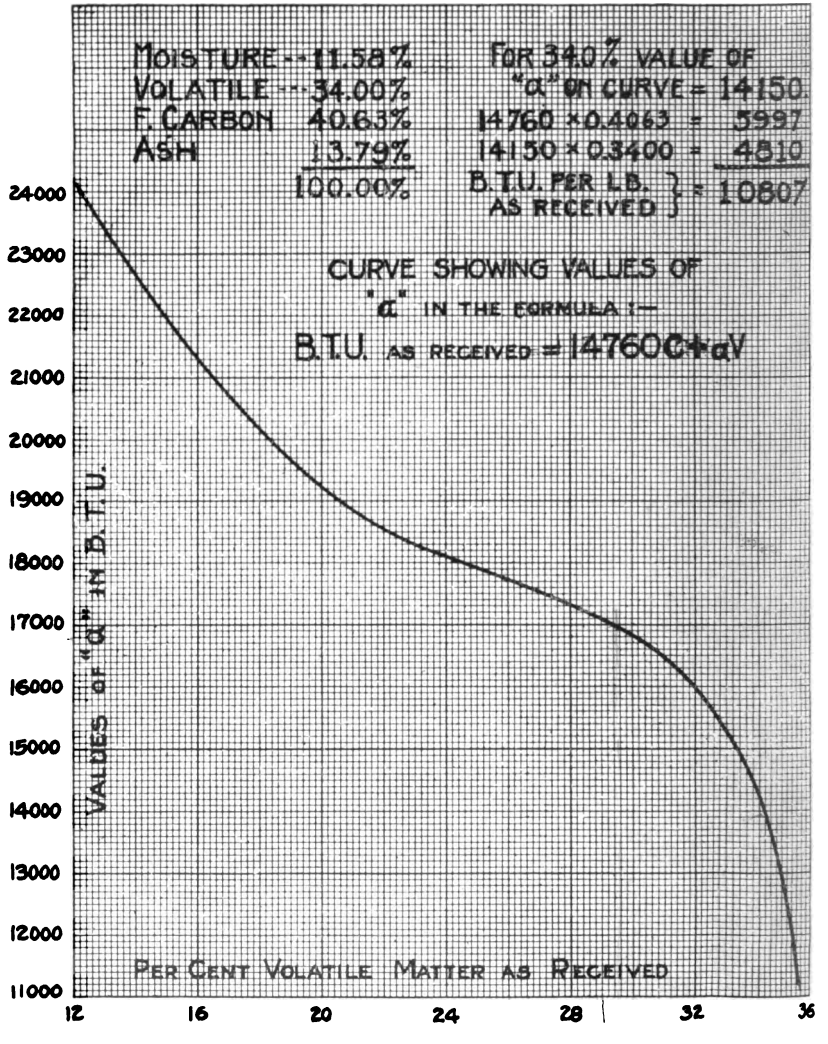

FIG. 16. COAL. CURVE AFTER GOUTAL FORMULA

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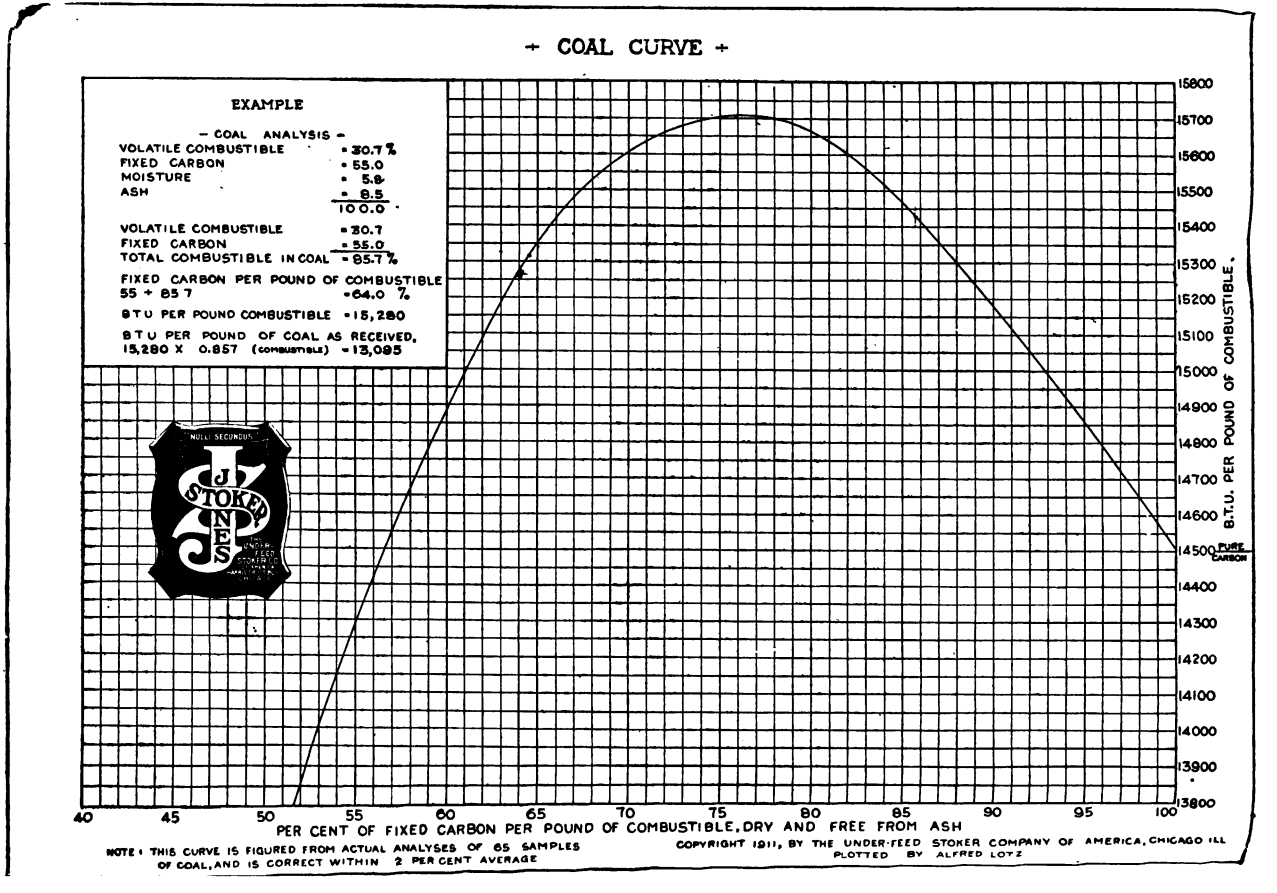

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further divided into one hundred divisions and thus $\frac{1}{1000}$ of a cubic foot can be read.

b. *Operation.*—By opening the cock on the water supply pipe introduce water into the calorimeter at (6) until the water will overflow in the weirs at both (8) and (13).

With the burner removed from the calorimeter, open the gas valve and allow gas to flow through the meter, the pressure regulator, and

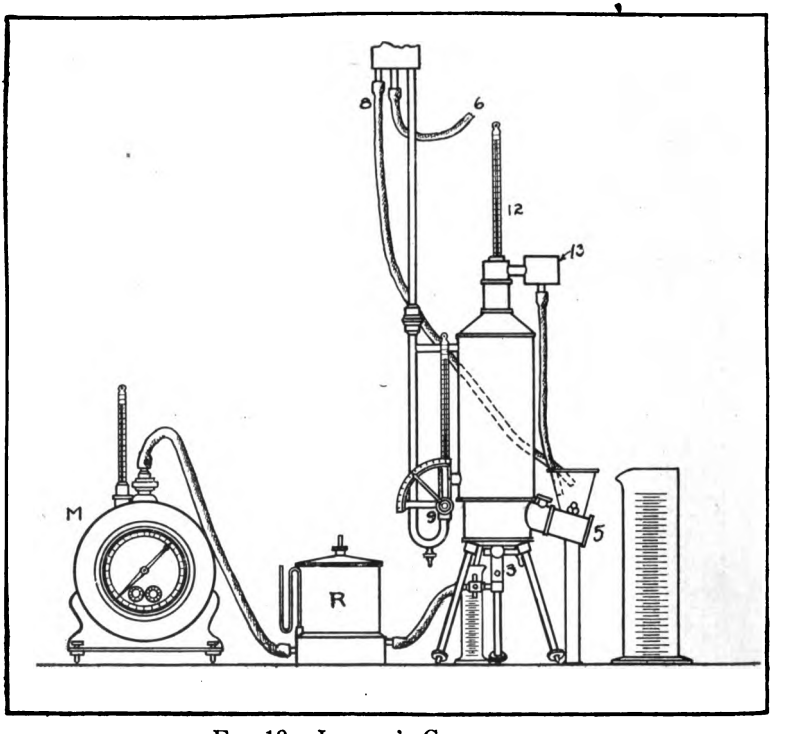

FIG. 18. JUNKER'S CALORIMETER

the burner. Light the burner, and by means of its regulating valve adjust the consumption of gas to a rate of between 7 and 8 ft. per hour or one revolution in 52 to 45 sec. respectively. Then insert the lighted burner into the combustion chamber. (Do not, under any circumstances, attempt to light the burner while it is in the calorimeter; an explosion will result which will wreck the apparatus.)

When the test is finished remove the lighted burner from the calorimeter. Do not turn off the gas while the burner is in the calorimeter.

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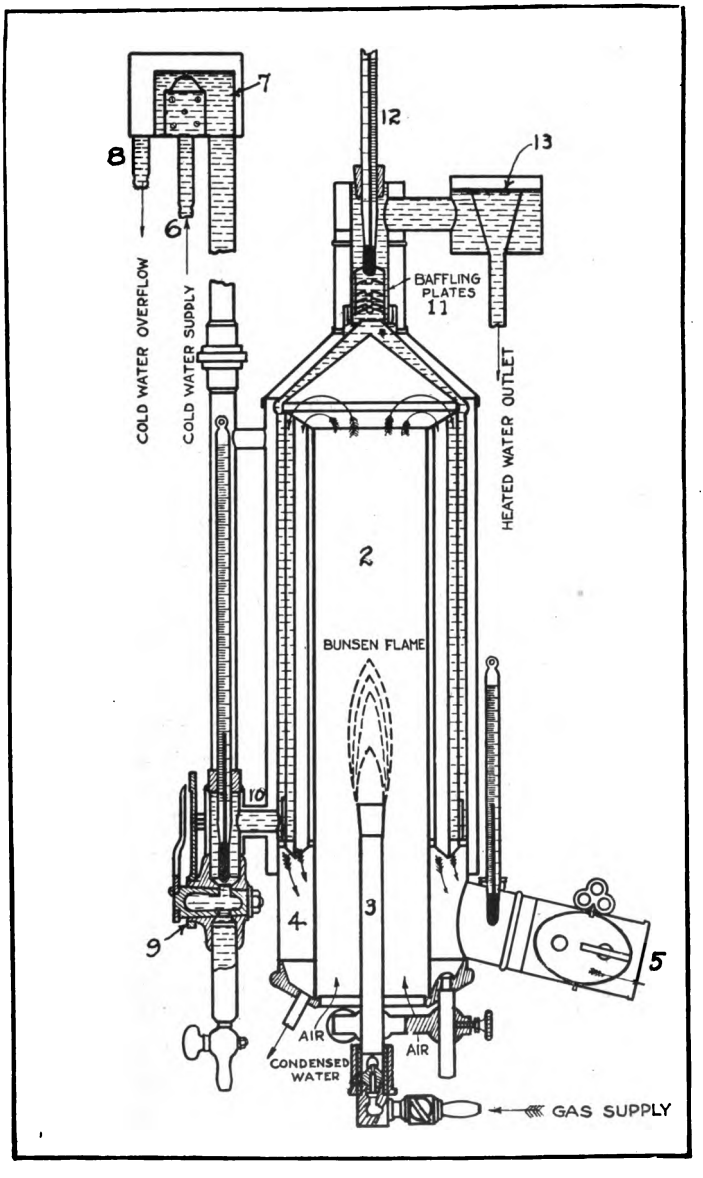

FIG. 19. SECTION OF JUNKER'S CALORIMETER

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By means of the regulating valve (9), adjust the flow of water so that the rise in temperature of the water as it passes through the calorimeter shall be between 15 and 20 degrees Fahrenheit, or 9 to 9.5 degrees Centigrade.

As the large hand of the gas meter passes zero, switch the water from the waste pipe into the weighing bucket and make as many observations of temperatures at the inlet and outlet as you can while 0.2 cu. ft. of gas is burned. When the hand of the meter passes through zero for the second time, switch the water from the bucket back into the waste pipe. Weigh the water thus obtained and find the differences between the averages of the inlet and outlet temperatures.

Observe the temperatures of the gas and the readings of the barometer, and from the tables in the appendix obtain the vapor tension at the temperature of the gas.

The temperature of the water entering the calorimeter should be about eight to ten degrees below room temperature, and the temperature of the products of combustion leaving at (5) should also be slightly below room temperature.

c. *Computations.*—Since the heat of combustion of the gas is given over to the water, then the product of the water heated and its rise in temperature, divided by the amount of gas burned, will give the heating value per cubic foot of gas.

The volume of a gas is dependent on the temperature and barometric pressure, and hence all gas volumes are referred to a standard. This standard as adopted by Gas Engineers is a cubic foot of a standard mixture of gas and water vapor at 60 degrees Fahrenheit and under 30 inches of mercury. The formula for correcting all observed volumes to this standard is given as

$$C = \frac{17.64\ (h - a)}{460 + t}$$

C = correction factor and is found as follows:

V = volume of gas under standard conditions of 30 inches of mercury and 60° F. with vapor tension of .518. This volume is unity.

V′ = volume at unknown pressure (h—a) for temperature (t) From Boyles and Charles law of perfect gases.

V:V′:: (30—.518) (460+t) : (h—a) 520

$$\text{Since } V = 1 \text{ then } V' = \frac{(h - a)\ 520}{(460 + t)\ 29.482}$$

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$$\text{or } V' = \frac{17.64\ (h-a)}{460+t} \quad V' \text{ is denoted by C}$$

h = barometer reading in inches of mercury plus gas pressure in pipe

t = temperature of gas as metered in Fahrenheit degrees

a = vapor tension in inches of mercury at the temperature (t)

To obtain the heating value under standard conditions, the above calorific value should be divided by the correction factor. The full expression, then, for heating value is

$$\text{B.t.u. per cu. ft.} = \frac{W\ (t'-t)}{VC}$$

W = weight of water in lb. caught during test

(t'—t) = difference between averages of inlet and outlet temperatures of water during test in degrees Fahrenheit

V = volume of gas burned in. cu. ft.

C = correction factor

For humidity correction curves for gas calorimeters see Appendix.

Other Forms of Calorimeters

The student is referred to Vols. III and IV (1908 and 1909 respectively) of the *Proceedings of the American Gas Institute* for detailed descriptions of various forms of gas calorimeters. Many calorimeters require a meter to measure the gas burned, notably the Junkers, Sargent, Simmance-Abadz, and the Boys. The Doherty and Parr calorimeters do not require a meter, and are unique in their construction and operation. A detailed description of these calorimeters would take up too much space here.

In writing up report follow out same idea as in previous two experiments, Nos. 26 and 27.

DETERMINATION OF THE COMPONENTS OF A GAS MIXTURE

a. *Principles.*—Usually the gases an engineer is called upon to analyze are mixtures of several components, such as oxygen (O_2), nitrogen (N_2), carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4) hydrogen (H_2), and a class of unsaturated hydrocarbons such as ethylene (C_2H_4), and benzene (C_6H_6) which together

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are usually called "illuminants" because of the luminosity which they impart to a flame.

The various components are separated from one another by shaking the mixture of gases with certain solutions which absorb or combine chemically with the gas. As each constituent is removed the resulting gas volume is smaller and a measurement of the volume before and after treatment gives a measure of the amount of the component. The various gases are removed by the following reactions:

(a) Oxygen by alkaline pyrogallol—absorption, action not well understood. Oxygen by yellow phosphorus—strong chemical reaction
(b) Nitrogen—no absorbent known
(c) Carbon dioxide by strong potassium or sodium hydrate solution—a strong chemical reaction
(d) Carbon monoxide by acid or ammoniacal cuprous chloride—reaction somewhat weak.
(e) Methane and hydrogen by explosion with oxygen or air
(f) "Illuminants" (benzene and ethylene) by strong bromine water or fuming sulphuric acid—a strong chemical reaction.

For further details of these reactions the student is referred to Winkler's *Technical Gas Analysis*, or Hempel's *Analysis of Gases.*

b. *Solutions.*—According to Winkler-Lunge.

Potassium hydrate solution for carbon dioxide is made by dissolving 250 grams of good commercial caustic potash in one liter of clean water. It is not necessary to use the potash purified by alcohol.

Sodium hydrate solution is made by dissolving the solid in three times its weight of water. This solution is cheaper but acts slower than the potassium hydrate.

Alkaline pyrogallol for oxygen is made by pouring 100 c. c. of the potassium hydrate solution over 5 grams of the solid pyrogallic acid. The solution takes place instantly and is ready for use. It should be kept away from air.

Fuming sulphuric acid for the "illuminants" is best purchased ready for use, and should have about 20 per cent free SO_3.

Bromine water for the "illuminants" can be made by saturating clean water with liquid bromine and keeping an excess of the bromine in the bottom of the bottle.

Ammoniacal cuprous chloride for the absorption of carbon monoxide is made by dissolving 250 grams ammonium chloride in 720 c.c. of water, and adding 200 grams of solid white cuprous chloride.

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The mixture must be agitated to dissolve the cuprous chloride. A spiral of copper gauze should also be placed in the bottle. To make the solution ready for use, it is mixed with one-third its volume of liquid ammonia and then kept in a double pipette.

EXPERIMENT NO. 29

FLUE GAS ANALYSIS WITH THE ORSAT APPARATUS

NOTE:—Read foregoing article with this experiment.

The gases commonly tested for in products of combustion from chimneys and flues are carbon dioxide (CO_2), oxygen (O_2), carbon monoxide (CO), and nitrogen (N_2). Since there is no quantitative absorbent known for nitrogen, the other constituents are determined first, and then the percentage of nitrogen is the difference between 100 per cent and the sum of percentages of the other components.

The Orsat apparatus, as shown in Fig. 20, consists of a wooden case with removable sides, containing the measuring burette (A) and the absorption pipettes (C), (D), and (E), all connected at the top by a branched capillary tube (F). Rubber bags are put on the free openings of the pipettes to prevent the air from spoiling the solutions. Each of these pipettes is filled with a set of glass tubes which give a large absorbing surface for the gaseous components.

This apparatus in its wooden case is portable and quite robust. It is fairly accurate when carefully handled and gives good results for the purposes of boiler tests.

Operation.—The test is made in the following manner. See that the solutions in pipettes (C), (D), and (E) fill the pipettes up into the capillary on top. This can be done by filling the measuring burette (A) with the leveling bottle (B) and then opening the pinchcock on (C) and lowering (B). The water in (A) flows into (B) and the air or gas in (C) flows into (A). When the liquid in (C) comes up to the pinchcock close the same. In this way adjust all pipettes. Then refill (A) with water from (B), attach the apparatus to the gas supply, and by lowering (B) the gas flows into the graduated tube (A).

Take 100 c. c. of gas into (A). Measure the same at atmospheric pressure by holding (B) so that the water level is at the same elevation as in (A). Now open the pinchcock on (C) which contains po-

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tassium or sodium hydrate, and drive the gas from (A) into (C). Draw gas back from (C) to (A) by lowering (B). Measure the volume left over by holding the surface of water in (B) on the same level as the surface in (A). Pass the gas into (C) again from (A), draw gas back and measure. If no change in volume has resulted the CO_2 has been removed. If the reading is not constant, repeat.

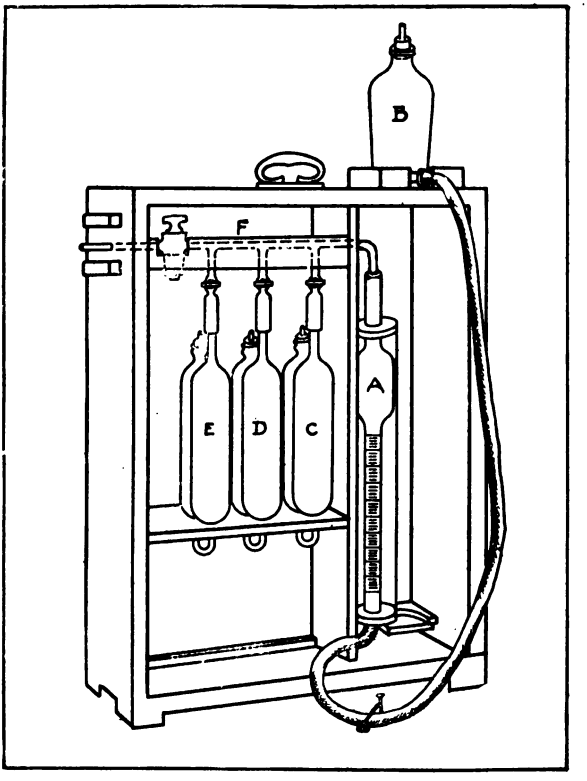

FIG. 20. ORSAT APPARATUS

Suppose reading on (A) is 91.5 c. c., then 100—91.5 = 8.5 c. c. of CO_2 or 8.5 per cent of CO_2.

Then absorb the oxygen by driving the gas into (D), which contains alkaline pyrogallol. When the oxygen is removed take out the carbon monoxide by passing it through the ammoniacal cuprous chloride in (E) in the same manner as the carbon dioxide was removed.

The water used in (A) and (B) should be saturated with the gas to be tested, or CO_2 will be taken up by the water.

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Calculation of Excess of Air

It is sometimes desirable to determine the excess of air supplied to the fire of a boiler or furnace. An approximate result can be obtained by using the results of the flue gas analysis with the Orsat apparatus. It must be assumed that the nitrogen in the flue gas all comes from the air, or that the nitrogen in the coal is negligible as compared to the nitrogen from the air. For this purpose it will be assumed that air consists of oxygen and nitrogen in the proportions by volume of 20.8 per cent and 79.2 per cent respectively. Then the nitrogen accompanying the free oxygen will be

$$N' = \frac{O_2 \times 79.2}{20.8}$$

Let N_2 = total Nitrogen

$N_2 - N'$ = nitrogen accompanying air necessary for combustion

Then $\frac{N_2}{N_2 - N'}$ = ratio of air used to air necessary, or making the required substitutions and solving, there results

$$\frac{N_2}{N_2 - \frac{O_2 \times 79.2}{20.8}} = \frac{N_2 \times 20.8}{(N_2 \times 20.8) + (O_2 \times 79.2)}$$

$$\frac{20.8}{20.8 - \frac{O_2 \times 79.2}{N_2}} = \text{ratio of air supplied to air necessary}$$

If 11.54 pounds of air are required per pound of carbon, and if the total carbon in the coal is determined, the actual air supplied is readily computed.

In your report include a write-up of the general method of conducting the experiment. Tabulate data neatly.

Experiment No. 30

GAS ANALYSIS WITH THE HEMPEL APPARATUS

For more complex gases, such as city and producer gas, the Hempel apparatus as shown in Fig. 21 is used. This apparatus permits of a greater accuracy than the Orsat, and is not difficult to operate, although great care must be exercised.

The components of a gas tested for with this apparatus, in the order in which they are removed, are: carbon dioxide (CO_2), with

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potassium or sodium hydrate solution; the "illuminants" (ethylene (C_2H_4) and benzene (C_6H_6) together) with fuming sulphuric acid or bromine water; oxygen (O_2) by alkaline pyrogallol; carbon monoxide (CO) by cuprous chloride; methane (CH_4) and hydrogen (H_2)

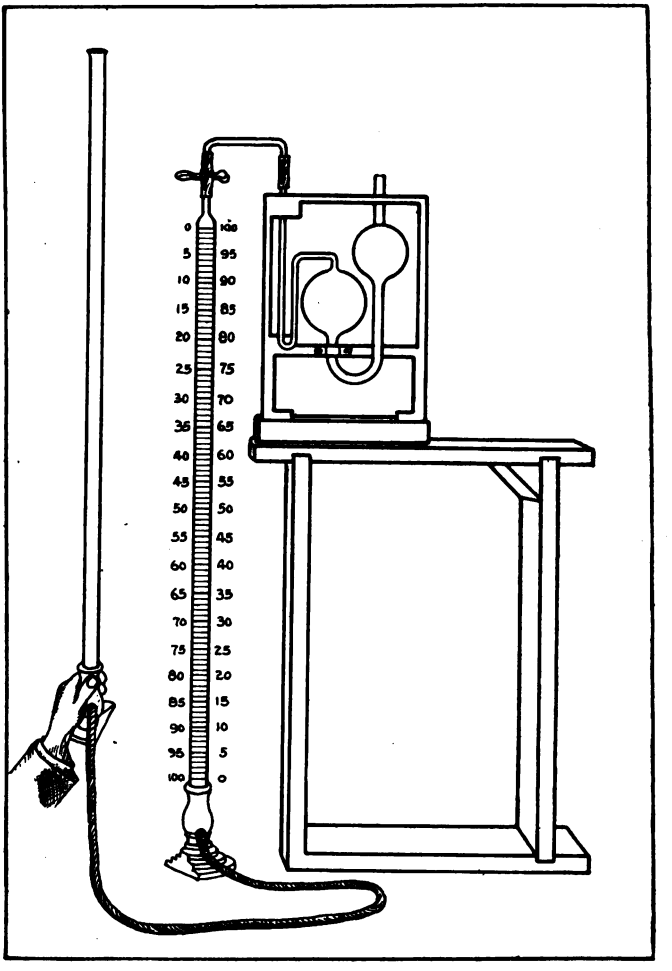

FIG. 21. HEMPEL APPARATUS

together by explosion and combustion; and nitrogen "by difference."

a. *Filling Burette.*—Open the pinchcock on the rubber tube connecting the burette and leveling tube; pour water saturated with the gas to be analyzed into the leveling tube until both tubes are about

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half full. Allow the water to flow into the burette until it is full. Close the pinchcock on the top of the burette and connect the latter to the gas supply by means of a bent piece of capillary tubing. Draw somewhat more than 100 c. c. of gas into the burette and allow it to drain. Close the burette on top. Compress the gas in the burette until the meniscus stands at 100 c. c., then open the pinchcock on top of the burette momentarily to release the pressure on the inside. Hold the leveling tube so that the surface of the water in it is on the same level as in the burette. Open the pinchcock on the rubber tubing connecting the burette and leveling tube; if the meniscus remains at 100 c. c. there is then confined in the burette 100 c. c. of gas at atmospheric pressure. In case the meniscus shifts from 100 c. c., repeat the above performance.

b. *Absorption.*—Connect the burette to an absorption pipette by means of a piece of bent glass capillary tube as shown in Fig. 21. First fill the small rubber connection on the burette with water by means of a medicine dropper; then insert the capillary tubing into the rubber and the water will fill the glass capillary; lastly, connect the glass capillary to the rubber connector on the absorption pipette. Drive the gas into the pipette by raising the leveling tube until the water from the burette fills the connecting glass capillary. Close the pinchcock on the burette and shake the pipette to give the gas good contact with the solution. After shaking for a couple of minutes draw the gas back into the burette by lowering the leveling tube until the solution from the pipette fills the connecting capillary. Close the top of the burette and bring the surfaces of water in the leveling tube and burette to the same level. Observe the reading of the bottom of the meniscus, after draining about three minutes. Repeat the above procedure until the reading is constant. In this manner absorb all the components in turn by the proper reagents. The methane and hydrogen are now determined by explosion.

The explosion test is made in a pipette, Fig. 22, containing mercury, and in the upper portion are two platinum wires fused in the glass on opposite sides. A spark from an induction coil is made to jump across the gap between the two wires and thus ignite the gas mixture in the pipette. The force of the explosion is of considerable magnitude and therefore caution must be used. ALWAYS see that the glass cock underneath the pipette is closed, and also that the rubber connection on the capillary is closed with a screw pinchcock. WHEN MAKING THE EXPLOSION ALWAYS HOLD A WIRE SCREEN BETWEEN YOUR FACE AND THE PIPETTE.

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Measure off in the burette from 12 to 15 c. c. of gas after having passed the cuprous chloride, and store the residue in a caustic pipette. Transfer the 12 or 15 c. c. to the explosion pipette and then measure off 85 c. c. of air and add this to the volume of gas taken in the explosion pipette. Close both cocks on the explosion pipette, shake a little to insure a thorough mixture, then ignite by closing circuit on induction coil.

After explosion transfer the gas back to the burette and measure the resulting volume. Then absorb the carbon dioxide formed and finally the oxygen left over.

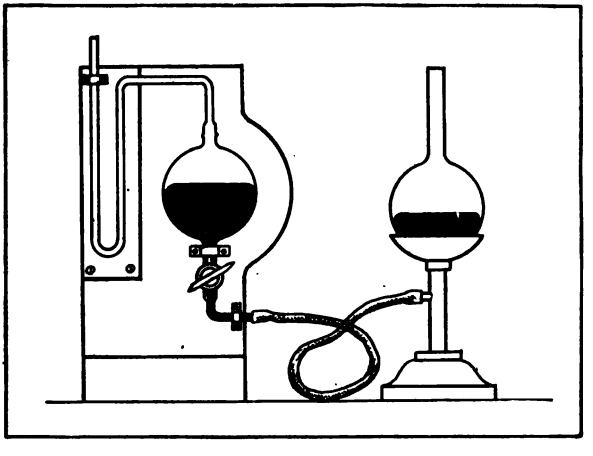

FIG. 22. EXPLOSION PIPETTE

An analysis of illuminating gas is here given for the sake of illustration. Took 100 c. c. of gas in burette, and passed the same into pipette containing KOH or NaOH. After absorption the volume measured was 97.00 c. c. Hence the CO_2 is 3.0 per cent. Passed the remainder into pipette containing bromine water. When chamber was filled with brown fumes, drew gas back into burette, disconnected, attached potassium hydrate pipette and passed gas into the latter. After the fumes of bromine were absorbed in the KOH, drew the gas back into the burette and measured. The reading is 86.0 c. c. Hence the "illuminants" equal 11.0 per cent. Absorbed oxygen in alkaline pyrogallol, and found reading after absorption to be 84.5 c. c. Therefore, oxygen equals 1.5 per cent. Passed the gas into ammoniacal cuprous chloride and after absorption found the reading to be 53.4 c. c. Therefore, CO equals 31.1 per cent.

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From the remaining 53.4 c. c. took 15 c. c. and stored the rest in a caustic pipette. The 15 c. c. were mixed with 84.5 c. c. of air and put into the explosion pipette. After explosion the volume measured was 78.2 c. c., and the contraction is 99. 5—78.2 = 21.3 c. c.

The remainder was now tested for CO_2 and after the absorption the reading was 74.0 c. c. Therefore, CO_2 equals 78.2—74.0 = 4.2 c. c. Then the residue was tested for oxygen and the reading after absorption found to be 69.2 c. c. Hence oxygen equals 74.0—69.2 = 4.8 c. c.

The reactions in the combustion are as follows:

(a) $H_2 + \frac{1}{2}O_2 = H_2O$

(b) $CH_4 + 2O_2 = CO_2 + 2H_2O$.

There are two unknowns here and it requires two equations. After the explosion, the contraction, the carbon dioxide, and the residual oxygen were determined. Since air contains 20.8 per cent of oxygen by volume, then in 84.5 c. c. of air there are 84.5 x .208 = 17.57 c. c. of oxygen. If there were 4.8 c. c. left over, then the amount used was 17.57—4.8 = 12.77 c. c.

From equations (a) and (b) it can be seen that the

(1) contraction $= \frac{3}{2}H_2 + 2CH_4$

(2) oxygen used $= \frac{1}{2}H_2 + 2CH_4$

(3) CO_2 formed $= CH_4$

These equations can now be solved for the content of H_2 and CH_4 in the 15 c. c. taken. Then in the remaining 53.4 the H_2 and CH_4 are solved for by simple proportion

$$\frac{H_2}{15} = \frac{y}{53.4}, \qquad y = 30.2$$

$$\frac{CH_4}{15} = \frac{z}{53.4}, \qquad z = 15.3$$

The nitrogen is determined "by difference." Subtract the sum of the constituents found from 100 per cent. The following check should be made on the test. If 84.5 c. c. of air were used for explosion, and of this amount 17.57 c. c. was oxygen, then 84.5—17.6 = 66.9 c. c. nitrogen. After the CO_2 and O_2 were removed there were left 69.2 c. c., which was nitrogen. If 66.9 c. c. nitrogen were brought in by air, then 69.2—66.9 = 2.30 c. c. nitrogen in the 15 c. c. of gas. Then 2.3 /15.0 = x /53.4 will give 8.2 c. c. the nitrogen in 100 c. c. of gas.

The complete analysis is now:

CO_2 = 3.00 per cent

CO = 31.1 per cent

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CH_4 =	15.3 per cent
O_2 =	1.5 per cent
H_2 =	30.2 per cent
N_2 =	8.2 per cent
Illuminants	11.0 per cent

For weights of gas per cubic ft. and heating value refer to experiment on the gas producer. Include in your report the calculations of the heating value of the gas from your analysis. Compare this with the results from the Junkers calorimeter.

In case all of the CO is not removed by the cuprous chloride the calculations are made as follows:

The reactions in the combustion are as follows:

(a) $CO + \frac{1}{2}O_2 = CO_2$

(b) $H_2 + \frac{1}{2}O_2 = H_2O$

(c) $CH_4 + 2O_2 = CO_2 + 2H_2O$

From equations a, b, and c, it can be seen that the

(1) contraction $= \frac{1}{2}CO + \frac{3}{2}H_2 + 2CH_4$

(2) oxygen used $= \frac{1}{2}CO + \frac{1}{2}H_2 + 2CH_4$

(3) CO_2 formed $= CO + CH_4$

In the above method it has been assumed that the residue after the carbon monoxide absorption consists of CO, CH_4, H_2, and N_2. This is the analysis in very common use. There is evidence that in the carburetted water gas there is present considerable amount of ethane, C_2H_6, which must be determined by combustion or explosion.

If the residue is assumed to be CO, H_2, CH_4, C_2H_6, and N_2 then the combustion goes as follows:

(d) $CO + \frac{1}{2}O_2 = CO_2$

(e) $H_2 + \frac{1}{2}O_2 = H_2O$

(f) $CH_4 + 2O_2 = CO_2 + 2H_2O$

(g) $C_2H_6 + \frac{7}{2}O_2 = 2CO_2 + 3H_2O$

Take 15 c. c. of the gas residue, mix with 85 c. c. of air and explode in the proper pipette in the usual manner. Measure the contraction in volume, the CO_2 formed, and the O_2 left over.

(4) Contraction $= \frac{1}{2}CO + \frac{3}{2}H_2 + 2CH_4 + \frac{5}{2}C_2H_6$

(5) O_2 used $= \frac{1}{2}CO + \frac{1}{2}H_2 + 2CH_4 + \frac{7}{2}C_2H_6$

(6) CO_2 formed $= CO + CH_4 + 2C_2H_6$

Here are four unknowns and only three equations, and more data is required. Take 30 c. c. of the gas residue and mix with 70 c. c. of air measured carefully in the burette. Connect the burette to a tube filled with palladium black and this to a pipette having water

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saturated with CO_2. Place the palladium tube in a beaker with hot water and pass the mixture back and forth from the burette through the palladium tube into the pipette until no further contraction takes place. (Do not allow any water to enter the palladium tube!) Measure the gas and the decrease in volume gives contraction due to H_2 and CO. Then determine the CO_2 formed.

The equations are:

(7) contraction $= \frac{3}{2}H_2 + \frac{1}{2}CO$

(8) CO_2 formed $= CO$

Combine equivalent values from (7) and (8) with (4) and (6), and the equations will give the correct amounts of the various gases present.

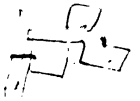
PYROMETRY

a. *Principles.*—It is frequently necessary to measure temperature about a boiler above 300 degrees centigrade, and a mercury thermometer will be found too fragile and small. Another method would, therefore, be more suitable. Of the several methods available for boiler and flue temperatures, the thermoelectric method is perhaps the simplest and cheapest.

This method consists of measuring on a millivoltmeter the electromotive force generated at the junction of two dissimilar wires when heated. Seebeck in 1830 discovered that when the junction of two dissimilar metals is heated an electromotive force, (e.m.f.), is set up at the junction. The e.m.f. so produced is a function of the temperature only and then only when the wires are homogeneous. If the circuit through these wires be closed through a millivoltmeter, a deflection of the needle results upon heating the junction.

b. *Choice of Couple.*—That couple which gives the highest e.m.f. for a given temperature, other things equal, is the best combination. For accurate work the couple devised by Le Chatelier is the best, but is rather expensive. The couple consists of platinum versus an alloy of platinum with 10 per cent of rhodium. This couple obeys a perfectly definite law and the equation of its calibration curve is a logarithmic one.

Owing to the high cost and the frail nature of the accessories of the platinum couple, there have been put on the market couples made of the baser metals, such as iron, nickel, chromium, and their alloys. Combinations of these metals give a high e.m.f. so that a double pivoted millivoltmeter can be used. The wires of these couples are



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usually large so as to resist oxidation and give mechanical strength. Most of these couples give fairly accurate readings up to 1,000 degrees centigrade and some may go to 1,400 degrees for a short time.

c. *Protection of the Wires.*—It is highly important that the wires be protected from contamination. Reducing flames in furnaces are injurious, so also the vapors of metals like zinc, antimony, silicon, and copper. The metallic vapors will alloy with the wires and destroy the couple. A protecting tube of iron, procelain or silica should be used to cover the couple when measuring temperatures where the wires would be contaminated when bare.

d. *Calibration.*—These couples had best be compared over the required range against a platinum couple, because the relation between e.m.f. and temperature is different for each combination. For details of calibration the student is referred to *High Temperature Measurements*, Le Chatelier, translated by G. K. Burgess.

e. *Operation.*—Insert the junction of the two wires into the space where the temperature is to be determined and read off the millivolts deflection. From the calibration curve the temperature corresponding to the millivolts is easily obtained.

GENERAL INSTRUCTIONS FOR INTERNAL COMBUSTION ENGINE EXPERIMENTS

The purpose of conducting these tests is the same as in the testing of steam engines and the general instructions for the operation of steam engines, as to care of the machinery, etc., as outlined in preceding experiments, is to be followed in gas engine testing.

Different types of gas engines require different methods of absorbing power; on slow-speed stationary engines having large flywheels the Prony brake will be used. On automobile or marine engines running at high speeds, either the water friction brake, fan dynamometer, or the electric dynamometer will be used. One type of water friction brake consists of a rotor similar to the impeller of a small water wheel enclosed in a housing. Water is admitted into the housing and the power absorbed by the churning action that takes place. The reaction of the housing is weighed on a platform scales as in case of the Prony brake. The load is varied by the quantity of water admitted to the housing, and by the pressure maintained in the housing. Another type of water brake consists of circular discs similar to large saws, without teeth, running in a

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bath of water. The bath of water is pivoted on trunions, and reaction weighed on a platform scales. The load is regulated by varying the depth of water.

The fan dynamometer merely consists of two blades mounted on opposite ends of a bar pivoted at the center. The necessary power to drive the fan at different speeds and for different settings of the blade has been previously determined by means of an electric dynamometer. In order to determine the horsepower delivered by an engine all that is necessary to know is the speed of the engine and the setting of the fan blades. Curves for horsepower output of two sizes of fan dynamometers will be found in Experiment No. 33.

The electric dynamometer consists of an electric generator with suitable field and armature control to regulate the speed and the output of the generator. In some cases the field of the generator is mounted on ball bearings, and reaction of the field is weighed on scales as in the case of a Prony brake. With the electric dynamometer it is necessary to know the friction horsepower of the machine at different speeds. The operation of the electric dynamometer is described in Experiment No. 34.

Gas engine indicators are different from steam indicators only in the size of the springs they use. In some cases where excessive pressure exists in the gas engine cylinder, it is necessary to use pistons of ½ or ¼ full size, in which case the scale of the spring has to be multiplied by the ratio of the piston areas. In taking an indicator card on a 4-cycle engine, the spring is too stiff to allow for a proper record of the intake and the exhaust stroke, and in order to obtain a record of the intake and the exhaust it is necessary to use a much more sensitive spring. When this is done the card is taken with the ignition system disconnected from the cylinder.

For taking indicator cards of an automobile engine, the manograph as described in Experiment 35 is used.

It is understood in these experiments that the student has had all the necessary information in the classroom regarding the cycle of operation of the different engines. If special information is desired by the student on any particular point, ask the instructor in charge.

Outline for Gas Engine 30 Reports

Title: Test on (name of engine).

Object: Inspection of engine, ignition system, and carburetor; starting of motor; adjusting of carburetor and ignition; study of operating features; and the running of an economy test. State clearly which of the above or other features were the principal objects of the test.

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APPARATUS: Description of test equipment under following heads:

1. Type of engine
   (a) Two cycle or four cycle
   (b) Vertical or horizontal
   (c) No. of cylinders
2. Class of engine—marine, automobile, stationary, etc.
3. Kind of fuel used.
4. Description of carburetor or other full feeding device.
5. Description of ignition system.
6. Speed control.
   (a) Hand throttle and ignition control
   (b) Automatic governor
      (1) Hit or miss
      (2) Quantity
      (3) Quality
7. Method of lubrication.
8. Method of loading for brake test.
9. Enumeration of any other apparatus, such as indicators, thermometers, scales, tanks, etc.
10. Description of any special features of equipment not included above.

METHOD: Describe the starting of the engine, adjustments made, and the effects of such adjustments. Tell of any difficulties encountered and how they were overcome. Tell what readings were taken, etc. State what maximum power was developed and how well the engine carried its rated load.

RESULTS: Show in tabular form the data taken during the runs and the results of each. Results should be shown in the following form:

FORM FOR RESULTS

Test No.					
Duration of test					
R.p.m.					
Brake load, lb. net					
Br. h.p.					
Total fuel per hr., lb.					
Fuel per B. h.p. hr., lb.					
Total fuel per hr., gal.					
Fuel per B. h.p. hr., gal.					
Total cost per hr.					
Fuel cost per B. h. p. hr.					

SAMPLE COMPUTATIONS: Give these for one run.

$$\text{Brake horsepower} = \frac{2\pi\ RNW}{33000}$$

CURVES: As required by instructor.

CONCLUSIONS: Draw up conclusions expressing your opinion on the results of the test and upon the good and bad points of the engine, etc.

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EXPERIMENT NO. 31

VALVE SETTING ON A 4-CYCLE GAS ENGINE

Due to the wear of an engine in continued operation, the valves of a gas engine get out of time, and in order that the engine delivers its rated horsepower, it is necessary to check up the valve setting frequently. Wear generally occurs on the cams, valve rods, tappet ends, and bearings. In this experiment either the International Harvester Engine or the Foos Gas Engine will be used. The dimensions of the different engines can be found in Experiments Nos. 32 and 38.

Find the head and crank end dead centers as previously outlined in experiment on slide valve setting and adjust the inlet valve and the exhaust valve for the proper settings. Angles and distances for setting the valves should be measured on the circumference of the flywheel. The manufacturers give the following settings for their engines:

VALVE TIMING FOR THE FOOS GAS ENGINE

Exhaust opens 45° early
Exhaust closes 5° late
Inlet opens 8° late
Inlet closes 30° late

With liquid fuels the ignition should be set so that the spark would occur about 15° early; with producer gas the spark should occur 35° to 40° early.

After the setting is completed the instructor in charge will demonstrate two different methods of starting the 4-cycle gas engine; one method being to follow the instructions as outlined by the manufacturer, using the relief cam; the other method being to put a combustible mixture in the cylinder and start the engine by ignition of this charge.

When the engine is operating successfully attach an indicator and adjust the spark for proper ignition. Determine the point for proper ignition and measure angles on the flywheel rim. Next put a light spring in the indicator and take diagrams of the suction and exhaust

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stroke. The instructor will demonstrate this operation. Do not in any case take a card until he has given the proper instructions or the result will be a ruined indicator.

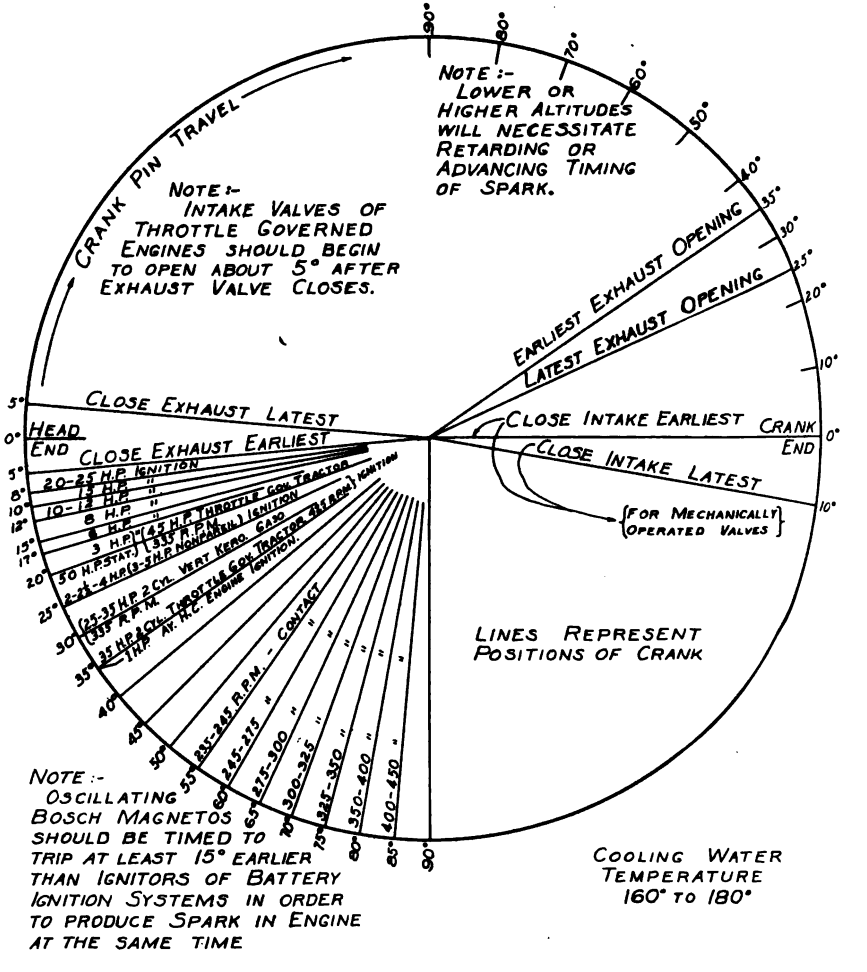
CRANK PIN TRAVEL
NOTE:- LOWER OR HIGHER ALTITUDES WILL NECESSITATE RETARDING OR ADVANCING TIMING OF SPARK.
NOTE:- INTAKE VALVES OF THROTTLE GOVERNED ENGINES SHOULD BEGIN TO OPEN ABOUT 5° AFTER EXHAUST VALVE CLOSES.
EARLIEST EXHAUST OPENING
LATEST EXHAUST OPENING
CLOSE EXHAUST LATEST
HEAD END
CLOSE EXHAUST EARLIEST
CLOSE INTAKE EARLIEST
CRANK END
CLOSE INTAKE LATEST
{FOR MECHANICALLY OPERATED VALVES}
20-25 H.P. IGNITION
10-12 H.P. "
8 H.P. "
3 H.P. (425 R.P.M. THROTTLE GOV. TRACTOR) IGNITION
50 H.P. STAT.) (325 R.P.M.
2-23-4 H.P. (3-5 H.P. NONPARKIN) GAS
(25-35 H.P. 2 CYL. VERT. KERO. THROTTLE GOV. TRACTOR (BEARN) IGNITION
325 R.P.M.
35 H.P. 4 CYL. THROTTLE GOV. TRACTOR (BEARN) IGNITION
1 H.P. AR. H.C. ENGINE IGNITION.
LINES REPRESENT POSITIONS OF CRANK
NOTE:- OSCILLATING BOSCH MAGNETOS SHOULD BE TIMED TO TRIP AT LEAST 15° EARLIER THAN IGNITORS OF BATTERY IGNITION SYSTEMS IN ORDER TO PRODUCE SPARK IN ENGINE AT THE SAME TIME
COOLING WATER TEMPERATURE 160° TO 180°

FIG. 23. VALVE TIMING DIAGRAM FOR I. H. C. ENGINES

REQUIREMENTS FOR THE PRELIMINARY REPORT AND FINAL REPORT

Your preliminary report should contain a description of the operation of the 2- and 4-cycle engine, naming the advantages and disadvantages of each; also include a description of the differences be-

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tween an automatic valve and a mechanically operated valve, and state the use of each.

Your final report should include a description of the general method of conducting the experiment, data, and results neatly tabulated, and a valve diagram showing the timing of the different events. Include a description of the different methods of speed control on a gas engine, namely, quantity, quality and hit-and-miss governing; also describe the ignition system and the carburetor.

Experiment No. 32

STATIONARY GASOLINE ENGINE TEST

In connection with this experiment, read over the general instructions for gas engine testing as outlined on page 144.

In the internal combustion engine, either liquid or gaseous fuel is drawn or forced into the cylinder with the proper proportion of air to form an explosive mixture. At a proper point in the stroke this charge is exploded and the pressure behind the piston is increased owing to the increase in volume of the charge and owing to the heat liberated by combustion. A portion of this increased energy is transformed into useful work on the power stroke of the engine.

When a gaseous fuel is used, it is a comparatively simple matter to mix it with air in the proper proportions to form an explosive mixture. When liquid fuels are used, it becomes necessary either to vaporize the liquid on its way into the cylinder or to spray it into the charge in the cylinder in the form of a fine mist. Gasoline vaporizes readily in a current of air and hence it is only necessary to provide a proper device to feed the gasoline over a surface so that it comes into intimate contact with the air supply. This device is known as a carburetor. In it the supply of gasoline may be controlled either by a float valve or by hand through a needle valve.

It is of the greatest importance that only enough gasoline be supplied to give a proper explosive mixture. The range through which the proportion of gasoline and air may be varied is very small and hence a careful adjustment must be made.

The student should study every mixing device and carburetor that he uses in his work and understand the principles of each. Some carburetors for automobile engines are assembled in such a way that great care must be exercised in dismantling them.

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The most important thing in gas or gasoline engine operation is to know what to do when trouble occurs. Besides performing commercial tests, the student should study carefully the operation of the unit and familiarize himself with the remedies for its more frequent troubles. The following paragraphs suggest some points along this line.

In starting an engine, if it fails to ignite its first, second, or third, charges, the cause of nonignition will not be removed by turning over the flywheel and will probably only be made worse by doing so. Better find the cause of the trouble and remedy it. This may be due to lack of fuel or to too much fuel, to lack of compression or to faulty ignition.

After the engine starts if there is popping or back firing in the pipe supplying the mixture, the engine may need more fuel, the admission valve may not close tightly, or the igniter may not be set at the proper time or may be otherwise out of adjustment.

Too much fuel in the charge is indicated by smoke issuing from the exhaust pipe.

A gas or gasoline engine can be shut down by supplying too much fuel just as easily as with an insufficient amount. For this reason, more power cannot be obtained from a cylinder by turning on more fuel after a certain mixture is obtained.

Loss of compression may be due to leaky valves or to worn piston rings. Leaky valves should be ground in at once. Worn piston rings must be replaced by new rings. The timing of the valves and of the igniter must be carefully adjusted.

Do not run the jacket water too cold. The temperature of the water leaving the jackets should be about 160° F.

The usual source of trouble is ignition. The wires or the electrodes themselves may be short-circuited. The spark points may be wet, gummed, or rusted. The batteries may be exhausted. A battery will usually last from two to six months, depending on the time the engine is in service and the care taken of the battery. Never leave the circuit with the switch closed after the engine is shut down.

When assembling piping to carry gasoline, never use red lead or oil on the joints. Clean them thoroughly and dope them with common yellow laundry soap before screwing up. Another good material is thick brown shellac but the threads must be cleaned of oil before the shellac is applied.

Pounding in the engine is sometimes caused by preignition or by too early ignition. In some cases a small amount of water vapor is

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injected or sucked in with the charge and greatly reduces the pounding at explosion.

The International Harvester gasoline engine is rated at 12 br. h.p. when running at 300 r.p.m. Its cylinder is 7½ in. x 11 in.

Directions for Test

Attach two speed counters, one to record speed and the other to read the number of explosions if engine has hit and miss governor.

Connect up an indicator to the reducing motion. Turn on the fuel supply and start up the engine. As soon as the engine starts, turn on the jacket water. Do not neglect this or an overheated cylinder will be the result.

Add load gradually until the proper amount is obtained.

Run four 20-minute tests at ¼, ½, ¾, and full load. Take indicator cards and other readings every five minutes during the test.

After the tests are completed, remove all load from the brake, and shut the engine down by shutting off the fuel and by opening the switch on the igniter circuit. Shut off the cooling water on the jacket.

In your report describe the carburetor and ignition system used on the engines if you have not performed Experiment No. 31. Describe the method of making the test and show the calculations involved in the general results.

The thermal value of the gasoline used in the laboratory averages about 20,000 B.t.u. per lb. This value may be used in working up the tests.

Plot curves with i.h.p. as abscissae and lb. of gasoline per i.h.p.-hour and thermal efficiency as ordinates. Also plot curves with br. h.p. as abscissae and total gasoline, lb. of gasoline per br. h.p.-hour and mechanical efficiency as ordinates.

Report log of test on farm shown.

The form for presenting the general results is based on the *A. S. M. E., Code* of 1915, for conducting tests on gas engines to which the student is referred. The complete code is in the back of the book.

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TEST OF.....GASOLINE ENGINE

Barometer..... Condition of atmosphere.....
Date of test..... Observers.....
Brake arm..... Dead weight of brake.....

Time	r.p.m.	Explosions	Temperature of Cooling Water		Quantity of cooling water	Brake load, lb.	m.e.p. cards	Pressures		Gasoline used, lb.	Room temperature		
			Inlet	Outlet				Maximum	Compression				

CALCULATION OF RESULTS

Numbering of paragraphs and tables corresponds with numbering in 1915 Test Code.

197a Volume of Gas at 60 deg. and 30 in.

The equivalent volume at a temperature of 60 deg. and at atmospheric pressure of 30 in. is obtained in the manner pointed out in ¶184a, *Test Code* 1915 which is included in the experiment on the gas producer.

197b Heat Consumption.

The number of heat units consumed by the engine is found by multiplying the heat units per lb. of oil or per cu. ft. of gas (higher value), as determined by calorimeter test, by the total weight of oil in lb. or volume of dry gas in cu. ft. consumed.

197c Horsepower and Efficiency

The indicated horsepower, brake horsepower, and efficiency are computed by the same methods as those explained in the *Steam Engine Code*, in ¶77, to which reference may be made.

197d Heat Balance

The various quantities showing the distribution of heat in the heat balance given in Table 20 are computed in the following manner:

The heat converted into work per i.h.p-hr. (2546.5 B.t.u.) is found by dividing the work representing 1 h.p., or 1,980,000 ft-lb., per hour by the number of ft-lb. representing 1 B.t.u., or 777.5.

The heat rejected in the cooling water is obtained by multiplying the weight of water supplied by the number of degrees rise of temperature, and dividing the product by the indicated horsepower.

The heat rejected in the dry exhaust gases per i.h.p-hr. is found by multiplying the weight of these gases per i.h.p-hr. by the sensible heat of the gas reckoned from the temperature of the air in the room and by its specific

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heat. The weight of the dry exhaust gases per i.h.p-hr. is the product of the weight of fuel per i.h.p-hr. by the weight of the dry gases per lb. of fuel. The latter is the product of the proportion of carbon in 1 lb. of fuel by the weight of the dry gases per lb. of carbon, which may be found by the formula

$$\frac{11\ CO_2+8\ O+7\ (CO+N)}{3\ (CO_2+CO)}$$

in which CO_2, O, CO, and N are percentages of the dry exhaust gases by volume.

When the weight of air supplied per lb. of fuel is determined the weight of dry gas per pound of fuel may be found by the formula

$$1+\text{lb. air per lb. fuel}-9H$$

in which H is the proportion of hydrogen in 1 lb. of fuel.

The heat lost in the moisture formed by the burning of hydrogen in the fuel gas is found by multiplying the total heat of 1 lb. of superheated steam at the temperature of the exhaust gases, reckoning from the temperature of the air in the room, by the proportion of the hydrogen in the fuel as determined from the analysis, and multiplying the result by 9.

The heat lost in superheating the moisture contained in the gas and air is determined by multiplying the difference between the temperature of the exhaust gases and that of the gas and air by the average specific heat of superheated steam for the range of temperature and pressure.

The heat lost through incomplete combustion is obtained by analyzing the exhaust gases and computing the heat of the unburned products which would have been produced by their combustion.

The above rules do not apply to engines with hit-and-miss governors.

DATA AND RESULTS OF GAS OR OIL ENGINE TEST

From Code of 1915

(1) Test of.....engine, located at.....
To determine.....
Test conducted by.....

Dimensions, Etc.

(2) Type of engine, whether oil or gas.....
(3) Class of engine, (mill, marine, motor for vehicle, pumping, or other)
(*a*) Number of strokes of piston for one cycle, and class of cycle.....
(*b*) Method of ignition.....
(*c*) Single or double acting.....
(*d*) Arrangement of cylinders.....
(*e*) Vertical or horizontal.....
(4) Rated power.....h. p.
(*a*) Name of builder.....
(5) Number and diameter of working cylinders.....in.
(*a*) Diameter of piston rods.....in.
(6) Stroke of pistons.....ft.

Date, Duration, Etc.

(7) Date.....
(8) Duration.....hr.
(9) Kind of oil or gas.....
(*a*) Physical properties of oil (specific gravity, burning point, flashing point).....

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Average Pressure and Temperature

(10) Pressure of gas near meter.....in. of mercury
  (a) Barometric pressure.....in. of mercury
(11) Temperature of gas near meter.....deg.
  (a) Temperature of cooling water, inlet.....deg.
  (b) Temperature of cooling water, outlet.....deg.
  (c) Temperature of air by dry-bulb thermometer.....deg.
  (d) Temperature of air by wet-bulb thermometer.....deg.
  (e) Temperature of exhaust gases at cylinder.....deg.

Hourly Quantities

(16) Calorific value of fuel per lb. (or per cu. ft. at 60° and 30 in).....B. t. u
(17) Gas or oil consumed per hour.....cu. ft., lb.
(18) Equivalent dry gas per hour at 60 deg. and 30 in.....cu. ft.
(19) Cooling water supplied per hour.....lb.
(20) Heat units consumed per hour (Item 16 × Item 18).....B.t.u.

Analysis of Exhaust Gases by Volume

(31) Carbon dioxide (CO_2).....per cent
(32) Carbon monoxide (CO).....per cent
(33) Oxygen (O).....per cent
(34) Nitrogen (N).....per cent

Indicator Diagrams

(35) Pressure above atmosphere.....lb. per sq. in.
  (a) Maximum pressure.....lb. per sq. in.
  (b) Pressure at beginning of stroke.....lb. per sq. in.
  (c) Pressure at end of expansion.....lb. per sq. in.
  (d) Exhaust pressure at lowest point.....lb. per sq. in.
(36) Mean effective pressure.....lb. per sq. in.

Speed

(37) Revolutions per minute.....r.p.m.
(38) Average number of explosions or firing strokes per minute.....
  (a) Variation of speed between no load and full load.....r.p.m.

Power

(39) Indicated horsepower.....i.h.p.
(40) Brake horsepower.....br. h.p.

Economy Results

(43) Heat units consumed by engine per i.h.p. per hour.....B.t.u.
(44) Heat units consumed by engine per br. h.p.....B.t.u.
(45) Dry gas at 60 deg. and 30 in. consumed per i.h.p.-hr.....lb., cu. ft.
(46) Pounds of oil or cubic feet of dry gas per br. h.p.-hr.....lb., cu. ft.

Efficiency

(47) Thermal efficiency referred to indicated horsepower.....per cent
(48) Thermal efficiency referred to brake horsepower.....per cent

Work Done per Heat Unit

(49) Net work per B.t.u. consumed (1,980,000 ÷ Item 44).....ft. lb.

Heat Balance

(50) Heat balance, based on B.t.u. per i.h.p. per hour.....

		B.t.u.	Per Cent
(a)	Heat converted into work	2546.5	
(b)	Heat rejected in cooling water		
(c)	Heat rejected in the dry exhaust gases		
(g)	Heat unaccounted for, including radiation		
(h)	Total heat consumed per i.h.p.-hr., same as Item 43		

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EXPERIMENT NO. 33

TEST OF AN AUTOMOBILE ENGINE WITH A FAN DYNAMOMETER

Read general instructions on page 144.

The general description, dimensions, etc., of the engine used in this test will be obtained at the time the experiment is performed, as the engines used in the laboratory are generally lent by the different companies and very few sections will run tests on the same engine.

The object of this experiment is to run a general test on an automobile engine, to become familiar with modern practice in this type of engine, and to determine the horsepower and efficiency at different speeds and loads.

The power will be measured by means of a fan dynamometer, consisting of two 10″ x 14″ aluminum plates bolted to a single arm. The arm has holes bored in it to allow for different positions of the plates. The dynamometer has been calibrated in its present position by means of a 40 horsepower motor and a horsepower speed curve determined for each position of the plates on the arm.

Directions.—Remove the spark plugs from the cylinders and see that they are perfectly clean; start the engine by means of the regular electric starting equipment and adjust the carburetor to its best working condition. Instructions for adjusting the carburetor will be found on a chart furnished by the instructor. When all adjustments are complete and the engine is in perfect running order, run four 15-minute tests at varying speeds; at ¼, ½, ¾, and full load, as nearly as can be obtained. Make an analysis of the exhaust gases to determine CO and oxygen.

Report.—The report should consist of a general description of the engine paying special attention to ignition, oiling system, carburetor, starting and lighting system, with a wiring diagram of the ignition and starting and lighting system.

Tabulate data and results as outlined in Experiment No. 32.

Plot curves between br. h.p. as abscissae and lb. of gasoline per br. h.p. hour and thermal efficiency as ordinates.

Gasoline 20,000 B.t.u. per lb.

The horsepower of the engine can be determined by means of the following curves.

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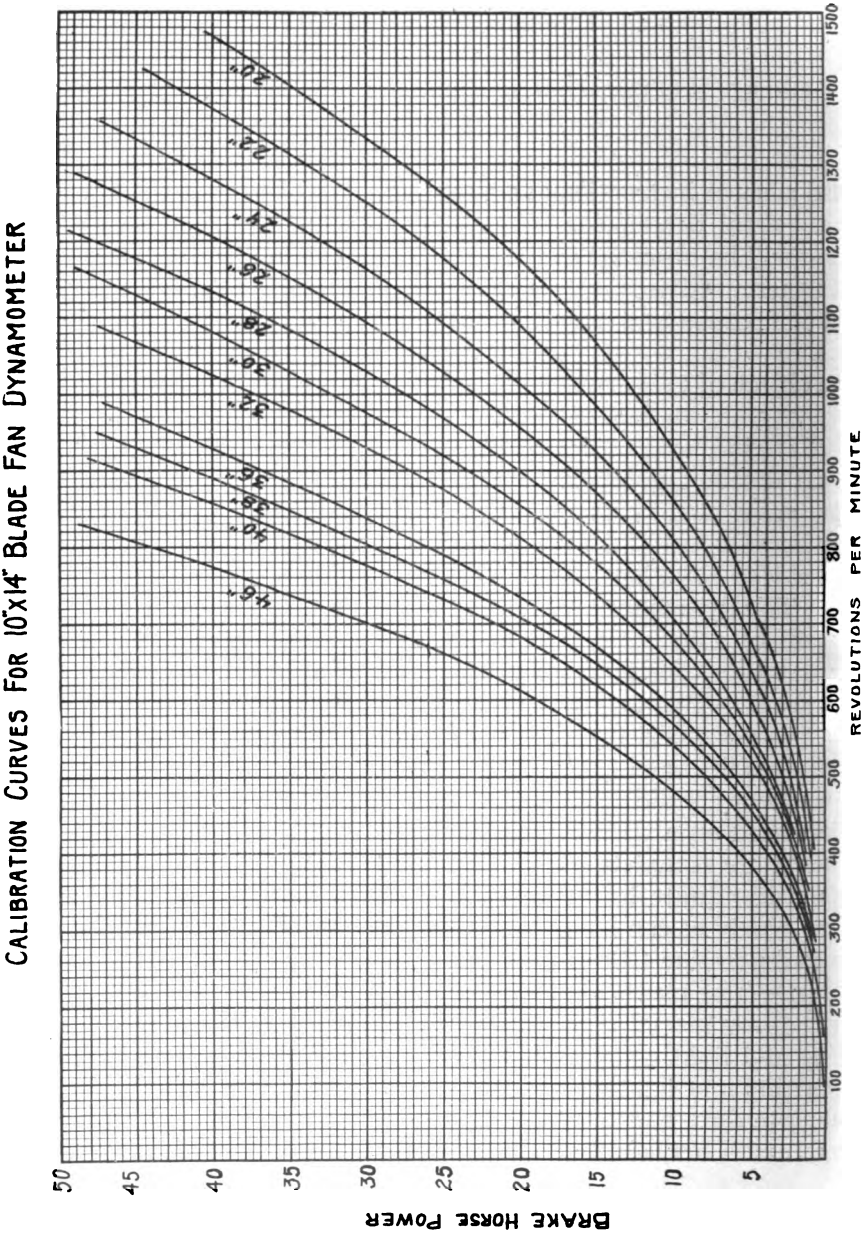

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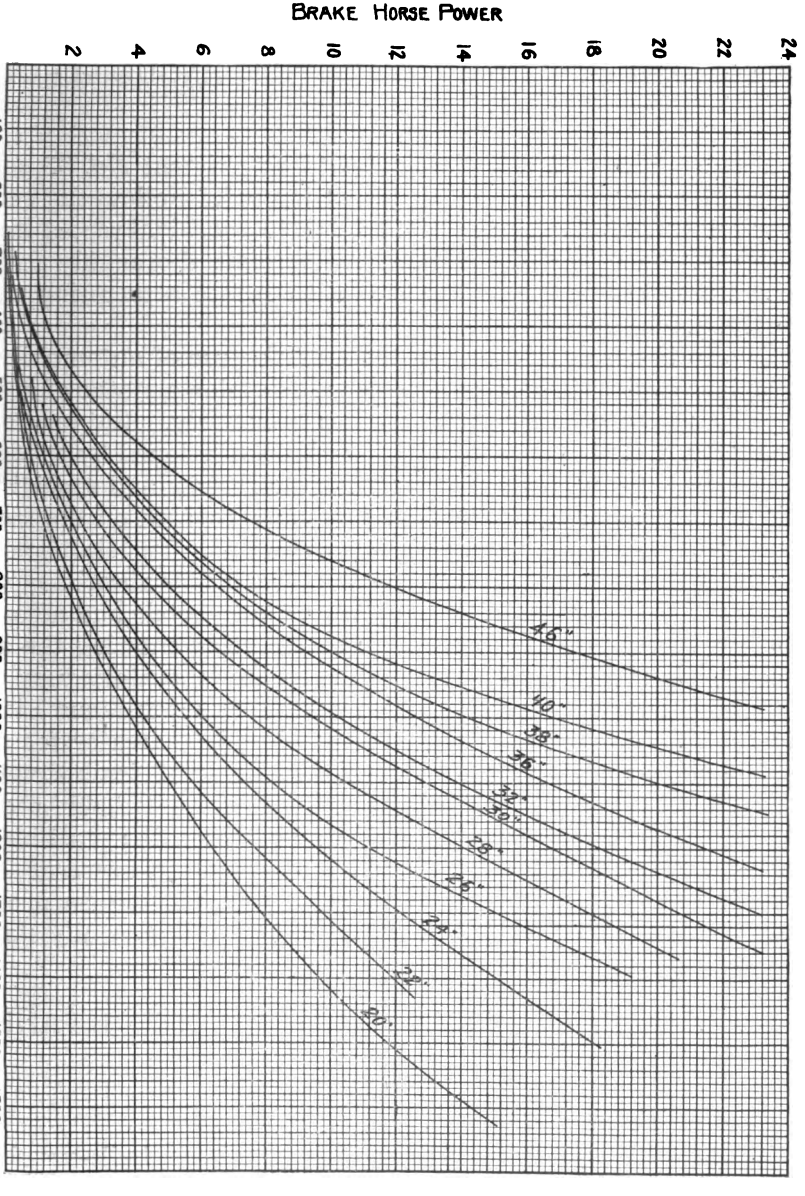

CALIBRATION CURVES FOR 6½"×8" BLADE FAN DYNAMOMETER

FIGURES ON CURVES REPRESENT DIAMETRAL DISTANCE FROM CENTER TO CENTER OF BLADES

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EXPERIMENT NO. 34

AUTOMOBILE ENGINE TEST WITH SPRAGUE ELECTRIC DYNAMOMETER

This experiment is exactly similar to Experiment No. 33, only a different method of measuring power is used. Follow the general requirements of Experiment No. 33, and in your final report include a description of the dynamometer. Become thoroughly familiar with the following method of operation before attempting to use the dynamometer.

Due to the rapid advance in the manufacture of automobile and aeroplane engines it became necessary to develop a means of absorbing the power of high speed engines accurately. Because of its flexibility, the electric generator has been developed by several of the leading manufacturers of electrical machinery and special electric dynamometer equipment can now be purchased on the market for taking care of the most exacting conditions. The electric dynamometer is now the standard piece of apparatus for absorbing power and wearing in engines in the majority of automobile and aeroplane manufacturing plants. Students contemplating entering the automobile field should study the machine in the laboratory very carefully as it is one of the very latest designs of the Sprague Electric Company. The big advantage of the electric generator for automobile and aeroplane engine tests lies in its great flexibility,—the variation in speed and load being practically unlimited, and the fact that if the engine misfires for a few revolutions, the machine will simply slow up temporarily, then pick up to normal speed after the trouble has been overcome. Where a Prony brake is used on an automobile engine if the engine begins to misfire it generally stops.

SPRAGUE ELECTRIC AUTOMATIC CONTROL PANEL

OPERATION

To Start a Motor:

1. Close field switch either way. If power is on, bulls-eye should light. If it is found that polarity or direction of rotation is wrong, reverse field switch.

2. Turn field rheostat hand wheel as far as it will go to the left, to give "full field."

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3. Close circuit breaker.

4. See that main dial switch handle is on the first (top) segment or near it. Exact segment on which to have dial switch handle not important, but the blade in handle should be squarely centered on a segment. Position of handle affects starting current as motor and load (speed) as generator. The nearer handle is to first segment, the less will be the starting current and the slower the start. This is also the position for lowest speed as generator.

5. *Push start button.* This causes contactor to close and admits current to dynamometer armature, and the dynamometer starts as motor cranking the engine.

To Load the Engine:

1. Start as described.

2. When engine is "firing," *push "stop" button,* and close the *single pole slow speed switch* at the left. This disconnects armature from line, and connects resistance in multiple for loading the dynamometer as generator.

3. To apply the load softly, *turn rheostat hand wheel rapidly to right* before closing the single pole switch, in order to weaken field. Then turn back again to increase load as desired.

4. Except when it is desired to pull down the engine to very low speeds, the handle of the main dial switch should be some distance around to the right.

5. The best position of the dial switch handle is that which will give the desired range of speed on the engine by field rheostat control only, without running up the amperes too high.

At very high speeds it is desirable to have the dial switch far around, either on the 13th, 14th, or 15th segment, counting clockwise.

6. For making tests on any one engine for speed-torque curve, a position of handle can be found giving a value of external resistance such that practically *entire range of speed* can be obtained simply with *field rheostat adjustment.*

To Make Tests of Friction Horsepower:

1. Start as directed.

2. To bring up to "normal" speed, move dial switch handle all the way around (clockwise).

3. To bring speed above "normal" bring dial switch handle all the way around (clockwise) and then turn field rheostat handle to right for further increase in speed.

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4. To obtain very low speeds, close slow speed switch. This connects resistance in multiple with armature as well as in series giving "voltage control," but drawing increased current from the line.

For Cranking and Loading Automatically:

In most cases engine can be started with low speed switch closed.

A position of dial switch handle can be found giving a medium load and speed for starting the test. This may be six or seven segments around from first point.

Leave dial switch handle in this position.

Close field switch.

Close circuit breaker.

Close slow speed switch.

Push "start" button—this cranks the engine.

Push "stop" button—this disconnects the line and leaves dynamometer loaded as generator.

Experiment No. 35

OPERATION OF HOSPITALIER CARPENTIER MANOGRAPH FOR INDICATING INTERNAL COMBUSTION ENGINES AND ALL VARIABLE PRESSURE ENGINES

The object of this experiment is to become thoroughly familiar with the method of recording pressures in internal combustion engines operating at high speeds and to become familiar with the different features of gas engine operation that can be analyzed by means of this machine.

Object of the Manograph

This indicator overcomes the inherent difficulty of the ordinary piston type indicator and indicates accurately at high speeds for which the piston indicator is useless.

The difficulties of the ordinary indicator are the excessive weight and inertia of its parts, such as piston, links, arms, and pencil, all of which must be moved by the engine in order to produce a diagram on the card.

The effect of these weighty parts is evident in lag and overrunning, resulting in untrue cards.

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The manograph substitutes a beam of light for these parts and this beam having no weight has none of the above defects and does delineate a true card.

The beam is provided by an electric lamp or arc light. The mobility of the beam is secured by reflecting it from a small mirror, which mirror is arranged to move in two distinct planes at right angles to one another.

The one movement is produced by and is a repetition of the piston movement. The other movement is produced by and is a faithful representation of the pressure existing in the cylinder.

Each movement taken separately would result in a straight line being shown by the beam of light on a ground glass screen and when pressure exists in the cylinder and the piston moves simultaneously the beam of light moves over the screen in accordance with the value of the two components and traces a line which forms a diagram.

That movement of the mirror which corresponds with the piston movement is effected by a flexible shaft which is attached to the crank shaft of the engine, the rotary motion thus obtained being transformed into the above described motion of the mirror by means of a small crank.

The pressure movement of the mirror is produced by means of a diaphragm which takes the place of the spring and piston of the ordinary indicator and is interchangeable with others for use with higher or lower pressures.

Either suction or combustion diagrams may be obtained with the same instrument, it being only necessary to change the diaphragm the same as a spring would be changed in an ordinary indicator.

Attachment to Engine

The method of attachment to the engine is remarkably simple, the flexible shaft being provided with a nose which is screwed into a tapped hole in the end of the crank shaft while the pressure pipe is provided with a steel cock to be screwed into the compression cock hole, into a valve cap or other convenient position.

Adjustment

The manograph is adjusted to absolute synchronism with the piston by removing the terminal from the spark plug and allowing the cylinder under investigation to operate without explosion. The diagram under these conditions should consist of an intake line and

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exhaust line, and the compression and expansion lines should be identical. If the compression and expansion lines are not identical, adjust the milled screw at the back of the manograph until they are. When the compression and expansion lines in the cylinder are identical the mirror is operating in synchronism with the piston. Synchronism having been obtained the spark plug lead can be replaced on the cylinder and the cylinder investigated under operating conditions for change of spark and throttle.

For visual observation the diagram is observed on the ground glass screen and temporary records may be made by following the line with an ordinary pencil.

Alterations of engine adjustment or conditions may be made and the result also traced with the pencil and the difference noted; thus no effort of memory is necessary to compare two diagrams.

Permanent records are made by substituting a photographic dark slide for the ground glass screen and exposing a plate to the action of the beam light, which plate is developed, and printed from in the ordinary way thus securing a record from which data may be taken for the determination of mean effective pressure, indicated horsepower, etc.

Directions for Test

Connect the manograph to the engine and make the necessary adjustments. Observe the effect on the shape of the diagram by advancing and retarding the spark, opening and closing the throttle, and changing the mixture.

Make sketches showing the shape of the diagram. Include these sketches in your report. If there is sufficient time make a set of photographic indicator cards by placing a film pack in the machine.

Experiment No. 36

TEST OF A HOT AIR ENGINE

A hot air engine is an engine whose piston is alternately driven backward and forward by the alternate expansion and contraction of a body of air caused by heating and cooling. It is principally used for light pumping service and may use either coal or gas as fuel. There are several types of this class of engine on the market, all differing slightly in the principles of operation. The change of tem-

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perature may take place at either constant volume or constant pressure, or the engine may work under the condition of receiving or rejecting heat at constant pressure.

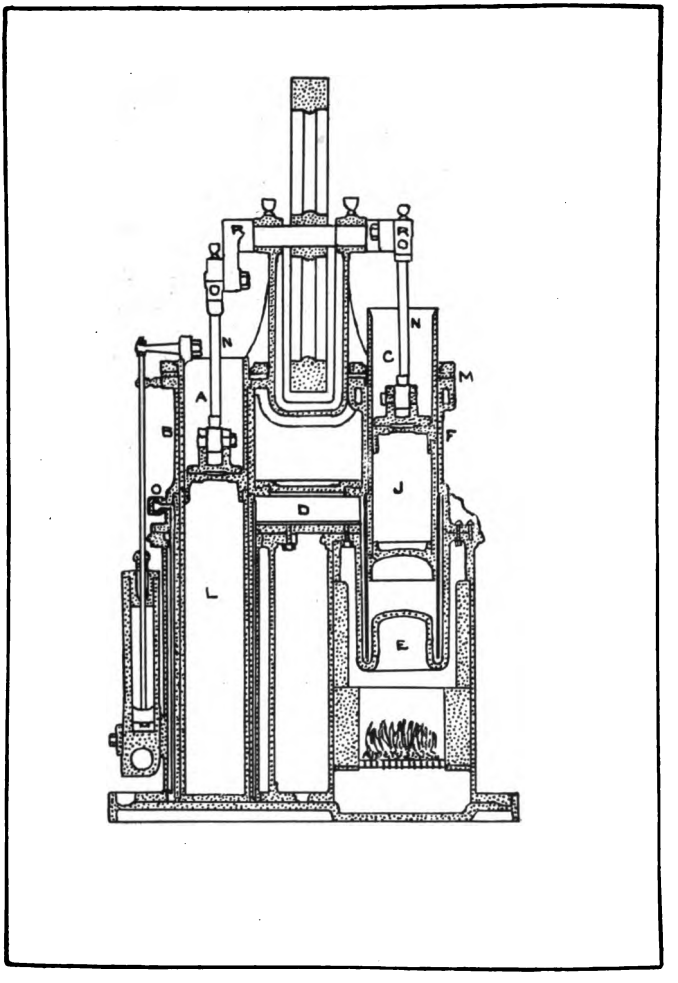

FIG. 26. HOT AIR ENGINE

Fig. 26 shows a section of a Rider Ericsson Hot Air Engine such as is in the laboratory. In this engine the compression piston A and the power piston C work in separate cylinders which are connected together by a rectangular passage D. A large number of thin metallic plates is placed in this passage thus forming a regenerator which al-

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ternately abstracts and returns heat to the air on its backward and forward movement through this passage. The same air is used continuously. Should any leak out, it is automatically replaced by the small check valve O opening inwards only.

The operation of the engine is as follows: The piston A compresses the cold air in the lower part of cylinder B which is known as the "Compression Cylinder." By the advancing or upward motion of the power piston C and the completion of the down stroke of the compression piston A, the air is transformed from the cylinder B through the regenerator D where it absorbs much heat, and into the power cylinder E without appreciable change in volume. The result is a great increase in pressure corresponding to the increase in temperature from the heat absorbed in the regenerator and from that added by the hot walls of the cylinder E which is kept heated by a gas jet below. This increase in pressure drives the power piston to the end of its stroke. The pressure still remaining in the cylinder now acts on the compressor piston A and forces it up till it reaches the top of its stroke. But the air is now being exposed to cold surfaces and rapidly cools. The pressure becomes a minimum when the power piston begins to fall transferring the air at almost constant volume to the compressor cylinder and compression is ready to start again. But while the heated air has been passing through the regenerator, a greater portion of its heat has been absorbed by the metallic plates. This heat is returned to the compressed air on the next stroke.

It will thus be seen that this engine works with practically change of temperature at constant volume.

The engine in the laboratory is used for driving a small water pump which is directly connected through suitable connecting rods to the piston in the compressor cylinder. The pump is provided with ball check valves and is double acting. The water raised by the pump is circulated through the water jacket of the compressor cylinder B before being discharged. The heat of the gas returning from the power cylinder is thus carried off by this water. The pump may be primed by pouring water into the funnel on its top, and by turning a cock, this is allowed to enter the pump.

Directions for Test

Oil up the bearings, cranks, and piston pins carefully. Apply a small amount of oily waste saturated with cylinder oil to the pistons

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while revolving by hand so as to lubricate them lightly. Do not put too much oil on the pistons or it will burn and cause them to stick.

Fill the jacket with water by priming the pump. Attach indicators to each cylinder with about 15 pound springs.

The net horsepower equals the difference between the work done in the power and in the compression cylinders.

Insert thermometers to take inlet and outlet temperatures of jacket water.

Attach a speed counter to take revolutions.

To start the gas burner proceed as follows: Before turning on the gas close the mixer. Apply a match to the burner at once after turning on the gas. Close the door and carefully open the mixer till the flame is blue.

The engine is ready to start when the heater above the gas burner or grate is a dull cherry red. Stand at the fire door and pull down the flywheel. Always have water circulating in the jacket above the power cylinder. Note the piping to produce this circulation.

The gas meter has no dial to indicate quantities of less than 1,000 cu. ft. except a small dial which reads 2 cu. ft. It is, therefore, necessary to take the time of flow of 2 cu. ft. on this dial at 10-minute intervals during the test and assume the average of these readings as representing the rate of flow throughout the whole test.

Note the reducing motions provided for the indicators and include description of same in your report.

Make 3 half-hour runs increasing the head five pounds at a time and taking indicator cards and other data every five minutes.

Keep logs on forms as shown and include a general report according to the following form.

To stop the engine, shut off the gas or draw fires. Close the mixer on the gas pipe. Open the fire door and let the engine run till cool.

Data regarding the engine are as follows:

	Power Cylinder	Compression Cylinder
Diameter	6¼ in.	6¾ in.
Stroke	9½ in.	8½ in.
Pump cylinder 1½ inch diameter	8½ in. stroke	
Pump piston rod ½ inch diameter		

Plot curves with total head lifted against as abscissae and both thermal efficiency and mechanical efficiency as ordinates.

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Test of Hot Air Engines

Made at..... Date.....

Barometer..... Indicator springs, power cyl.....
compression cyl.....

Diam. power piston..... Stroke, power cyl.....
compression cyl.....

Area, power piston.....

Diam., compression piston.....

Area, compression piston..... Observers.....

Time	r.p.m.	Pressure			Room temp. °F.	Jacket Water			Gas meter reading cu. ft. per min.	Compression Cylinder		Power Cylinder		Net i.h.p.	Gas temperature
		Suction ins. vac.	Discharge water lb.	Gas pres. in. water		Entering temp. °F.	Discharge temp. °F.	Wt. of water lb.		m.e.p.	i.h.p.	m.e.p.	i.h.p.		

Test of.....Hot Air Engine

Made at..... Date.....

Diameter of pump plunger..... Stroke of pump.....

Diameter of pump plunger rod..... Barometer.....

B.t.u. per cu. ft. of gas at standard conditions (60° F. and 30 in. mercury).....

Observers.....

1.	Suction head, ft.....			
2.	Head pumped against, ft.....			
3.	Total head, ft.....			
4.	Water delivered, lb. per hour.....			
5.	Foot-pounds of work done.....			
6.	r.p.m.			
7.	Plunger displacement per hour, cu. ft.....			
8.	Slip, per cent.....			
9.	Indicated h.p., power cylinder.....			
10.	Indicated h.p. compressor cylinder.....			
11.	Net indicated h.p.....			
12.	Developed h.p.....			
13.	Mechanical efficiency.....			
14.	Cu. ft. of fuel per hour at standard conditions (60° F. and 30 in. mercury).....			
15.	Range of temperature of jacket water, °F.....			
16.	Heat supplied per hour, B.t.u.....			
17.	Heat equivalent to indicated work, B.t.u.....			
18.	Heat absorbed by water jacket, B.t.u.....			
19.	Heat loss in radiation, B.t.u.....			
20.	Heat supplied per indicated h.p., B.t.u.....			
21.	Thermal efficiency, per cent.....			
22.	Actual duty, ft. lb. per million B.t.u.....			

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EXPERIMENT NO. 37

OIL ENGINE TEST

There are several different makes of fuel oil engines in the steam and gas laboratory, but only one of these will be described here. When tests are assigned on one of the other engines the general directions in this test will be followed, and the general data and results as outlined in Experiment No. 32 are to be followed.

The principal problem in the use of liquid fuel in internal combustion engines lies in the vaporizing. As gasoline vaporizes readily in air at ordinary temperatures, its use is attended with no special difficulties. Other fuels such as crude oil, kerosene, etc., are not so readily vaporized but are cheap and abundant in some parts of the country. Hence many methods have been tried to make them available for use in specially designed oil engines. In some engines, the fuel is sprayed in a fine mist into highly compressed air in which it burns as it enters. An example of this type is the Diesel engine. In other engines it is sprayed onto a heated surface which vaporizes and ignites it when the mixture has been compressed. This is the method used on the Mietz and Weiss engine which will be tested in the laboratory.

Fig. 27 shows a section of this engine.

The operation of this engine is as follows: Air is drawn into the closed crank case from the interior of the base through a port which is overrun by the piston. On the forward stroke of the piston, i. e., toward the crank, the piston covers this port and compresses the air in the crank case. Near the outer end of this stroke the piston uncovers the exhaust port in the bottom of the cylinder through which the gases behind the piston escape. At about the same time a port on the top of the cylinder is uncovered through which the compressed air in the crank case together with the steam generated in the water jacket, passes into the cylinder. This air helps to scavenge the cylinder. Just after the exhaust port is closed by the piston on its return stroke, the fuel is injected into the cylinder by a small pump and is instantly vaporized by falling on a lip attached to a hot bulb but projecting into the cylinder. This bulb is not water-cooled.

On the return stroke of the piston the mixture is compressed and ignited by the bulb which is nearly red hot at all times.

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The kerosene is contained in a tank mounted on the top of the crank case. The oil pump is operated automatically by a lever arm from an eccentric on the shaft. A small hand lever is provided to pump in oil for starting.

The speed is governed by varying the supply of fuel. A shaft governor varies the throw of the eccentric that operates the oil pump

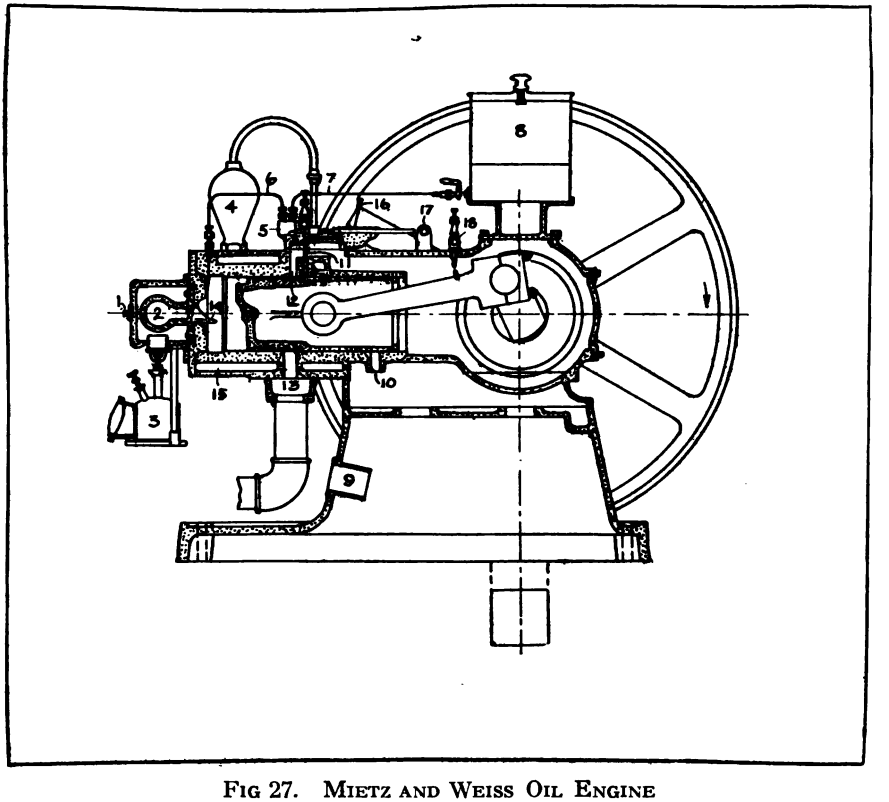

FIG 27. MIETZ AND WEISS OIL ENGINE

and thus the stroke of the pump supplying fuel is varied according to the load.

The ignition takes place when the charge is compressed into the hollow bulb. When starting up this bulb must be heated with a torch until it will ignite a charge. This engine is an example of the "hot tube" method of ignition. It is simple and has proved successful in practice.

The jacket is cooled by a supply of water so controlled by a float that the water evaporates in the jacket and the steam formed

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passes with the air from the crank case into the cylinder. The presence of steam in the compressed charge helps to form a mixture of high specific heat and thus reduces the danger of preignition and also allows of higher compression pressure. As there is no continuous flow of water, a very small quantity is required in the jackets as compared with a gasoline engine.

The crank and piston are oiled from sight-feed lubricators from an oil tank on the side of the cylinder. The crank case runs partly full of oil and hence splash lubrication is provided.

Care must be taken not to pump in too much kerosene and thus flood the cylinder.

In this engine the heat absorbed by the jacket water is equal to the heat of vaporization times the weight of water evaporated in the jackets.

Directions for Test

Connect indicators both to crank case and to cylinder, the former with a light spring and the latter, a regular gas engine indicator, with heavy spring. Note and describe the reducing motion in your report. Start torch under bulb and get it heated to a red heat.

Turn water on the cylinder float box.

Turn engine over by hand a few times to see that oil is feeding to cylinder, crank pin, etc.

When bulb is hot, pump in some kerosene by hand and pull the engine over. It should pick up its own explosions after a few revolutions.

Add load to the brake and run four tests.

Take indicator cards from both ends every five minutes.

Keep logs on form shown for gasoline engine, making such changes as are necessary to adapt it to kerosene. The results can also be reported on the gasoline report, substituting kerosene for gasoline, and drawing similar sets of curves.

This engine has a cylinder 4½ in. x 6½ in. and runs at 500 r.p.m.

There are two other kerosene burning engines in the laboratory, the Chicago Pneumatic Tool Engine and the St. Mary's H. O. Engine.

The Chicago Pneumatic Tool Engine operates on the 2-cycle principle, but has a cross head, and it compresses the air on the front side of the piston, instead of using the crank case as in the case of the Mietz & Weiss Engine. This engine also introduces water into the combustion space, but the water goes in as a spray and not as

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steam. The dimensions of this engine are: piston 12″ x 12″ stroke, piston rod 2″ diameter.

The St. Mary's Engine operates on the 4-cycle principle and ignites the fuel by means of high compression. The compression in this engine is 600 lb. to the square inch. No water or water vapor is introduced into the cylinder. The dimensions of the engine are, cylinder diameter 4¾ inches x 6 inches stroke.

In conducting tests on these engines follow the general instructions in the previous experiment, and work up the data and results according to the forms of Experiment 32.

Experiment No. 38

TEST OF A GAS ENGINE

Note:—Read instructions on page 144.

The main characteristics of internal combustion engines have been pointed out in describing the gasoline engine test. The instructions and method of testing outlined in that experiment apply also to the gas engine with the exception that the fuel in the latter case is gaseous instead of liquid.

The most important determination is the measurement of the gas supplied. This may be measured by gasometers, by gas meters, by Venturi meters, by Pitot tubes, or by Thomas electric meters. The three latter instruments are considered under the experiment on "Measurement of Gases." When using gasometers or gas meters, the temperature of the gas and also its pressure must be accurately recorded during a test.

Where it is desired to analyze the fuel or exhaust gases, a continuous sample may be taken throughout the test, or samples may be taken at regular intervals. These can be analyzed in Hempel apparatus. The heating value should be determined in each case by means of a Junker's calorimeter.

When gas is supplied under pressure it is usual to provide a gas bag to take up the engine pulsations. This usually consists of a chamber provided with a flexible rubber diaphragm over one end.

It is sometimes desirable to measure the air taken in per stroke. This may be done by special meter arrangements or by orifice measurements. For further information on this subject the student is referred to Royd's *The Testing of Motive Power Engines.*

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Laboratory Tests

The Foos engine was built especially for the University for experimental purposes. It is provided with a firm sub-base carrying a counterbalanced disc crank shaft with two heavy flywheels. The cylinder is held to the base by a flange on each side in line with the center of the cylinder so that expansion can take place freely. The valves are placed in cored extensions, one on either side of the cylinder. These chambers, together with the cylinder and cylinder heads, are thoroughly water jacketed. The valves are positively operated by cams on a shaft geared 2 to 1 from the main shaft so that the engine is a 4-cycle unit. The valves are vertical and are closed by springs. A plug on the top of the valve chamber on either side may be easily removed, giving access to the valves for inspection or regrinding or for inspecting the igniter. The plug on the inlet valve chamber carries a small priming cup, while the plug on the exhaust valve chamber has been tapped to receive an indicator cock.

The igniter consists of a small revolving pin which carries a lip on the portion inside the cylinder and which is geared from the cam shaft. With each revolution of the pin, the projecting lip wipes the end of an insulated spring strip and produces a large spark when contact is broken. This wiping action tends to keep the surface clean and bright. The time of ignition can be adjusted while the engine is in operation by turning a thumb screw on the revolving pin.

The cylinder head is water-cooled and is perfectly plain in outside appearance. The engine is provided with three different heads, each so constructed that it provides the necessary clearance space to produce the proper compression when used for the fuel for which it is adapted. One head is for use with artificial or city gas, a second for use with gasoline, kerosene, or crude oil, and a third for use with producer gas.

The engine is also provided with two sets of governors, one for throttling, and the other for hit-and-miss regulation. The horizontal centrifugal fly-ball governor is used for the latter system and the speed can be altered while the engine is in operation.

There is also provided the necessary carburetors, control valves, gas bags, oil heaters, etc., necessary to form eight complete and different engine arrangements for different fuels and for the two methods of governing. The engine is also provided with a special valve for water injection in the charge when kerosene or similar fuel is used.

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When the engine is operated with a throttling governor, it should be noted that while the inlet valve opens every second stroke, the fuel valve is only opened when the governor is at or below normal speed. Hence during the strokes in which no fuel is supplied the fresh air is drawn in, compressed and discharged with the exhaust, thus materially aiding in scavenging the cylinder and improving its efficiency.

The exhaust from the engine passes into a Riblet heater in which water is circulated. The amount of heat recovered from the exhaust gases can be determined by the inlet and outlet temperatures and weight of this cooling water. The piping is so arranged that either the jacket water or cold water can be run through the heater. If this recovered heat could be utilized in a heating system of a building or shop, the thermal efficiency of a gas engine system would be greatly increased.

It is desirable in gas engine tests to know the condition of the air entering the engine. Hence the humidity should always be determined by wet and dry bulb thermometers. For humidity calculations, the student is referred to the chapter on Hygrometry.

The Foos engine has an 8¾ in. by 14 in. cylinder. Its normal speed is 270 r.p.m. and it is rated at 20 br. h.p. Its brake arm is 3 ft. 6 in. long.

Directions for Test

Attach an indicator with a 240 or 320 pound spring and adjust the reducing motion.

Provide thermometers for gas, room, inlet, and outlet jacket water and (if taken) exhaust temperatures. Also provide wet and dry-bulb thermometers for humidity determinations.

Attach a water gage to read the pressure of the gas.

Provide thermometers for the water inlet and outlet temperatures on the exhaust heater and measure the amount of water passing through.

Start the engine and run four 20-minute tests at ¼, ½, ¾, and full load.

Take cards and readings every 5 minutes.

The log form and general statement of results shown for the gasoline engine can be used on this gas engine with such changes as provision for pressure, temperature, and volume of gas. In the case of the Foos engine, the temperatures and weight of water in the

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exhaust heater and the exhaust gas temperatures must also be provided for.

Plot curves with i.h.p. as abscissae and mechanical efficiency, thermal efficiency, total gas, and cu. ft. of gas per i.h.p.-hour as ordinates.

Also plot curves with br. h.p. as abscissae and thermal efficiency and cu. ft. of gas per br. h.p.-hour as ordinates.

Experiment No. 39

TEST OF GAS PRODUCER AND ENGINE

One of the most important sources of cheap power at present is the gas engine which derives its fuel supply from a gas producer. The advance in the art within the last few years has been so phenomenal that a careful study should be made of the problem of producing power by this means. The work in the steam and gas laboratory on gas producers will be made to cover as nearly as possible the principles involved under actual operating conditions.

The fundamental principles of the production of producer gas are as follows: The coal or other fuel is fed through a hopper into the cylindrical chamber of the producer, which consists of a steel shell heavily lined with fire brick. This hopper is usually provided with doors arranged so that coal can be fed without loss of gas. The producer may or may not be provided with grates, depending on whether the producer is of the up or down draft type and whether it has a water seal or not.

The coal drops down from the hopper on the top of the fuel bed in the body of the producer. Anthracite coal of pea size is usually used in suction producers.

There is one rebuilt Wile suction gas producer in the steam laboratory. This producer has a Fairbanks-Morse saturator.

In the suction type the air enters below the grates and first combines with the carbon to form CO_2. The air, however, is supplied in insufficient quantities for the complete combustion of the whole mass of fuel. Hence the CO_2, in passing through the next layer of fuel above, is broken up and forms CO, which together with the inert nitrogen passes out through the top of the fire unaltered as there is no free oxygen to unite with it.

The student is referred to a textbook dealing with gas producers for a full treatment of this theory.

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Air may be forced under the grates, in which case we have a pressure producer, or air may be drawn through the grates and fuel bed, by the suction of the piston of the engine or of an exhauster forming a suction producer. Steam is usually drawn or blown in through the producer with the air. It serves two purposes, one to cool the grates and fuel bed and the other to enrich the producer gas by the addition of hydrogen. When the steam meets the incandescent carbon, water gas ($CO + H_2$) is formed. The dissociation of the steam into H_2 and O to form water gas is a heat absorbing process and hence cools the fuel bed of the producer.

The steam may be produced in a suitable chamber by utilizing the heat of the gases leaving the producer or it may be obtained from some other source. In the Fairbanks-Morse producer, it is evaporated in a circular trough around the top of the producer. The air is first drawn over the surface of this trough and becomes saturated with steam. It then passes down to the bottom of the producer and up through the grates and fuel bed. Some other types of producer have a small cylindrical boiler on end, through which the gas passes before entering the scrubber and gives up its heat to the water in the boiler. The resulting steam is then led into the air intake of the producer.

The supply of steam is thus regulated by the demand of the engine for gas. If this demand increases, more gas leaves the producer and the fire would tend to get hotter. But more steam is produced in the vaporizer and this again keeps the fire from becoming hotter. Hence the regulation of the temperture of the fuel bed is automatic.

After passing through the vaporizer, the gas next enters the bottom of a cylindrical tower known as the scrubber. It is brought into contact with water falling in a fine spray from the top. This removes the heavier dust particles and cools the gas for use in the engine. Sometimes this tower is filled with broken coke or limestone. In other plants it consists merely of a cylindrical tower with a fine water spray.

In some plants the gas is next passed through a dry scrubber to remove moisture, tar constituents, etc. This scrubber consists of a cylindrical chamber containing beds of coke or wood shavings. Where bituminous coal is used in the producer or where blast furnace gas is used, the gas is usually passed through a rotary scrubber known as the Theisen washer. Water is thrown out in a thin film by centrifugal force. As the gas passes through this film the solid particles and condensed tars are almost entirely removed.

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When determinations of dust and moisture in the gas are desired, the student is referred to H. J. Freyn's paper on "Blast Furnace Gas Power Plant," Vol. 32, *Transactions A. S. M. E.*, for methods of making such tests.

Tests of gas producers may be made to determine the quantity, composition, and heat value of the gas produced, its impurities or moisture, the efficiency of the producer, its heat losses, or the power required by the auxiliaries.

In testing a gas producer the object of the test should be clearly defined and the test carried out to provide the data required.

Before firing up, the producer should be examined and its condition noted, the size of the grates should be measured together with the height and diameter of the producer itself. All clinkers should be removed from the walls and all soot and dust from the passages and flues. The character of the fuel should be determined and also its B.t.u. contents per pound. A method of sampling and quartering should be followed out to obtain an average sample, which sample should be tested in a coal calorimeter.

All apparatus such as weighing scales, thermometers, pyrometers, pressure and draft gages, etc., used in the test should be calibrated.

When an auxiliary boiler is used to provide a supply of steam, the fuel used must be charged against the producer.

Before starting tests the producer should be brought to its working temperature and all conditions made steady. The conditions at the end of the test should be the same as at the beginning, i. e., the fire should be the same in depth and the same in its condition, and the walls, flues, etc., at the same temperature.

If possible, the rate of gasification should be kept constant through the tests. The tests should be of sufficient duration to give good average results under working conditions. Uniformity of conditions should prevail during the tests as to pressure of steam, air blast, thickness of fire and depth of ashes, the time of firing, the quantity of coal fired at one time, the frequency of poking, and the intervals between cleaning fires. Make a note in your record of these events during test.

Determine the amount of steam supplied to the producer.

After the test, weigh the ash, and, by air drying a sample, correct for moisture and also for combustible.

Samples of the gas should be analyzed for CO_2, CO, H_2, O, and N. A portion should also be passed through a gas meter and burned under a Junker calorimeter for a determination of its heating value.

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In determining the heating value of the gas it should be stated whether the "high" or "low" heating values are used. The standard "high" heating value is defined as the heat from combustion per cu. ft. of standard gas at 60° F and 30 in. barometer when the products of combustion are brought back to 60° F and the moisture condensed. If the moisture is not condensed, it gives the "low" heating value.

The gas leaving the producer may be measured by passing it through a gas meter, or a Venturi meter, by measuring with an orifice or Pitot tube, or by calculation from chemical analysis. The latter method is very common and is based on the assumption that the carbon as shown by the ultimate analysis of the coal burned, must appear again in the gas, and hence the quantity of gas can be determined by computation. This method is shown in Carpenter & Diederich's *Experimental Engineering*.

The coal and ash should be weighed, sampled, and analyzed during the test in the same manner as in a boiler test.

If it is desired to determine the efficiency of combustion in the engine, samples should be taken of the exhaust gases and analyses made by means of the Hempel apparatus.

Determine the humidity of the air in the producer room.

The grate efficiency of a producer is defined as

$$\frac{\text{Total heating value of fuel—Heating value of fuel lost in ashes}}{\text{Total heating value of the fuel fired}}$$

The commercial efficiency of the producer is the ratio of the total heat in the gas to the total heat in the coal burned.

Tests on gas producers should extend over a long period, preferably a week if possible. The body of the producer holds a quantity of coal which is large compared with the amount actually burned in a period of a few hours. It is very difficult to determine whether this coal bed is in exactly the same state as regards quantity, temperature, and ash, at the end of a test as at the beginning. Hence less errors are liable in long tests. It is desirable to have all labortory tests extend over at least 24 hours.

Directions for Test

Poke down the producer and add fresh fuel. Blow up the fire with the blower until a good quality of gas is passing out from the waste pipe—as shown by test flame which should be straw colored.

While this is being done, put the various thermometers in place and attach draft gages, indicators, etc. Also connect up sampling pipe

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to supply Junker's calorimeter and to sample the gas for analysis by Hempel apparatus. An aspirator may be used for the latter purpose.

Oil up the engine carefully. Place a brake on the brake wheel and find its constants. Take the speed by means of a continuous counter. Provide means for weighing the cooling water from the engine jackets.

When good gas is being made at the engine, start it with compressed air. This is necessary on account of the high compression required by producer gas.

On account of this high compression and the resulting high explosion pressure, indicator springs of 200 or 250 pounds should be used.

When the engine is running at a fair speed, cut off the air and throw on the gas. The mixing valves on starting should be set for a strong gas mixture. When the engine is up at speed, these valves should be readjusted and checked by means of indicator cards. As the quality of the gas often changes from time to time, it is necessary to readjust the mixture to the engine during the test to suit conditions.

Measure the inlet and outlet temperatures of the jacket water, and if practicable the temperature of the exhaust.

The test on the engine will be the same as that for a gas engine and the same log form may be used.

On a 24 hour test of the producer and engine, readings need be taken at 10 minute intervals only.

During the test keep close watch on your producer. See that no holes or dead spots form in the fuel bed, through which air can pass and dilute the gas. Poke down the fuel when these form. Keep the fuel bed even and of uniform quality. Try to produce a uniform quality of gas.

Report data and results on the following form:

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TEST OF GAS PRODUCER AND ENGINE

Log of test of gas producer

Size of producer..... Barometer.....
Date of test..... Observers.....

Time	Weight of coal	Weight of steam used	Water used in scrubber	Draft		Temperatures							
				Ash pit	Flue	External air	Producer room	Air entering ash pit	Gas leaving producer	Water entering scrubber	Water leaving scrubber	Gas leaving scrubber	Water entering vaporizer

CALCULATION OF RESULTS

184a Total Volume of Gas Delivered

The volume of gas in the case of Pitot tube measurement is determined by multiplying the area of the delivery pipe in sq. ft. at the tube by the velocity of the gas in ft. per minute, and the product by the duration of the trial in minutes.

The equivalent volume at atmospheric pressure (30 in. barometer) and temperature of 60 deg. Fahr., is obtained by multiplying the measured volume by the absolute pressure of the gas in lb. per sq. in. (gage pressure plus barometer pressure) and by the constant 35.3, (520 ÷ 14.7), and dividing the product by the absolute temperature of the gas (temperature by thermometer plus 460 deg.)

The gas as it leaves the scrubber is saturated with water vapor at the pressure due to the temperature, and this pressure is to be deducted from the absolute pressure as observed, to obtain the net pressure of dry gas. The volume of dry gas in that case is obtained by the following formula:

$$V = V_e \times \frac{P - P_w}{P_a} \times \frac{520}{t + 460}$$

in which V =equivalent volume of dry gas at 60 deg. and 30 in. leaving scrubber
V_e=observed volume of gas leaving the scrubber
P =absolute pressure at the point where the volume is measured
P_w=pressure of saturated water vapor at temperature
P_a=atmospheric pressure (14.7 lb. per sq. in. or 30 in. of mercury)
t=observed temperature of gas leaving scrubber

P and P_W are to be taken in the same units at P_a.

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The volume of dry gas delivered by a gas producer can be obtained by calculation from the analyses of the coal and of the dry gas, by the following method:

$$\text{Dry gas per lb. carbon} = \frac{11\ CO_2 + 8\ O + 7\ (CO + N + C_2H_4) + 4\ CH_4 + 0.5H}{3\ (CO_2 + CO + CH_4 + 2\ C_2H_4)}$$

in which CO_2, O, CO, H, CH_4, C_2H_4, and N are percentages of the dry gas by volume. Multiplying the lb. of gas per lb. of carbon by the percentage of carbon in the coal and dividing by 100 gives the weight of dry gas per lb. of coal, and the volume of gas per lb. of coal is found by dividing this weight by the weight of one cubic foot of the gas calculated from the analysis as shown in Paragraph 184c below.

The weight of carbon per 100 cu. ft. of gas can be found directly from the analysis by multiplying the percentage by volume of each gas containing carbon by the pounds of carbon in 1 cu. ft. of the gas as given below:

$CO + CO_2$, 0.03173; CH_4, 0.03176; C_2H_4, 0.06345

and adding the results together.

84b Net Volume of Dry Gas Delivered

The net volume of dry gas delivered is found by subtracting from the total volume the volume of gas that would be required for furnishing steam or power for any purpose concerned in the operation of the producer and its auxiliaries.

84c Weight of Gas

The weight of dry gas delivered is found by multiplying the volume in cu. ft. reduced to 60 deg. and 30 in. pressure, corrected for moisture, by the weight per cubic foot, which is found by multiplying the percentage of each component gas as found by analysis by its weight in lb. per cu. ft. at 60 deg. and 30 in., as given in the following table (calculated from Landolt and Börnstein's figures at 32 deg.), and dividing the sum of the products by 100.

H	0.005335	CO_2	0.116333
O	0.084608	CH_4	0.042434
N	0.074082	C_2H_4	0.074113
CO	0.074029	SO_2	0.169400

84d Calorific Value of Gas

The calorific value of the dry gas per cu. ft. is obtained by means of the Junker calorimeter but it may also be obtained from the analysis by multiplying the percentage of each combustible constituent gas by its heating value per cu. ft. at 60 deg. and 30 in. as given below:

	B.t.u. per cu. ft.		B.t.u. per cu. ft.
CO	317.8	CH_4	1002.1
H	329.9	C_2H_4	1595

These figures are the product of the above values of weight of gas per cu. ft. by the heating value of one pound of gas according to Thomsen.

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184e Moisture in Gas

The moisture in the gas leaving producer, is found by passing a measured sample of the gas through a chloride of calcium tube and weighing the amount of moisture absorbed.

The moisture in the gas leaving the scrubber is best found by calculation assuming that the gas is saturated with moisture. The calculation is made in the manner pointed out in Paragraph 184a.

184f Percentage of Tar and Soot in Gas

The percentage of tar and soot is found by comparing the total weight determined, including that collected from the various tar drips with the total weight of dry fuel used.

184g Efficiency

The efficiency is the relation between the calorific value of the dry gas per lb. of dry fuel charged or combustible, and the calorific value of 1 lb. of dry fuel or combustible. The former is ascertained by multiplying the B.t.u. per cu. ft. of dry gas as determined by the calorimeter test (higher value) by the cu. ft. of dry gas delivered, and dividing the product by the total weight of dry fuel charged or combustible.

The "combustible" is determined by subtracting from the weight of coal charged the moisture in the coal and the weight of ash refuse and unburned coal withdrawn from the producer or ash-pit during the progress of the trial. The "combustible" used for determining the calorific value is the weight of the coal less the moisture and ash found by analysis.

The efficiency of "conversion and cleaning" or "gross efficiency" in the above calculation is found by using the total volume of gas delivered. The "efficiency of the plant" or "net efficiency" is found by using the net volume of gas delivered.

184h Heat Balance

The various quantities showing the distribution of heat in the heat balance given in Table 19, are computed in the following manner:

The calorific value of the dry gas is found by multiplying the cubic feet of gas at 60 deg. and 30 in. per lb. of dry coal by the calorific value of 1 cu. ft. of gas at 60 deg. and 30 in. (higher value).

The sensible heat in the dry gas is found by multiplying the weight of gas per pound of coal by the mean specific heat of the gas and by its temperature measured above 60 deg.

The heat carried away by the scrubber is obtained by multiplying the weight of water fed to the scrubber by the number of degrees rise of temperature, and dividing the product by the total weight of dry coal consumed.

The heat contained in the moisture leaving the producer is found by multiplying the total weight of dry gas per lb. of dry coal by the proportion of moisture in the gas and by the total heat of 1 lb. of superheated steam at the temperature of the gas leaving the producer reckoned from 60 deg.

The loss due to combustible matter in the ash is found by multiplying the proportion that this combustible bears to the whole amount of dry coal by 14,600 B.t.u.

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Data abd Results

185. The data and results should be reported in accordance with the form given herewith (Table 19), adding lines for data not provided for or omitting those not required as may conform to the object in view. If a shorter form is desired, the items in fine print designated by letters of the alphabet may be omitted. Unless otherwise indicated, the items should be the averages of the data.

186. If a preliminary trial of the fuel is made in a test-producer, add to the table the general results obtained.

Chart

187. In trials having for an object the determination and exposition of the complete performance from beginning to end, the entire log of readings and data should be plotted on a chart and represented graphically.

TABLE 19 DATA AND RESULTS OF GAS PRproducer TEST

Code of 1915

(1) Test of.....producer located at.....
To determine.....
Test conducted by.....

Dimensions, Etc.

(2) Outside diameter and height of producer.....ft.
(3) Inside diameter of producer.....ft.
(4) Area of grate diameter.....sq. ft.

(a) Percentage of air space in grate.....per cent
(b) Area of blast inlet.....sq. ft.
(c) Area of exit flue.....sq. ft.

(5) Area of fuel bed (at maximum diameter).....sq. ft.

(a) Area of water heating surface in vaporizer.....sq. ft.

(6) Rated capacity of producer in lb. of coal per hour.....lb.

Date, Duration, Etc.

(7) Date.....
(8) Duration.....
(9) Kind and size of coal*.....

* If other fuel than coal is used the lines may be changed to read accordingly.

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Average Pressures, Temperatures, Etc.

(10) Steam pressure in vaporizer by gage.....lb. per sq. in.
(11) Gas pressure in main at point where gas is measured.....in. of water
- (a) Pressure at top of producer.....in. of water
- (b) Pressure beyond scrubber.....in. of water
- (c) Pressure beyond purifier.....in. of water

(12) Force of blast or draft in ash pit, or bottom of producer.....in. of water
- (a) Barometric pressure.....in. of mercury
- (b) Relative humidity of air.....per cent
- (c) Depth of fuel bed.....
- (d) Intervals between cleaning.....
- (e) Intervals between poking.....

(13) Temperature of feedwater entering vaporizer.....deg.
- (a) Temperature of gas in exit flue at producer.....deg.

(14) Temperature of gas in main at point where gas is measured.....deg.
- (a) Temperature of air in room.....deg.
- (b) Temperature of water entering scrubber.....deg.
- (c) Temperature of water leaving scrubber.....deg.

Total Quantities

(15) Weight of coal charged*.....lb.
(16) Percentage of moisture in coal.....per cent
(17) Total weight of dry coal.....lb.
(18) Total ash and refuse.....lb.
(19) Percentage of ash and refuse in dry coal..... per cent
(20) Total combustible (Item 17 — Item 18).....lb.
(21) Total number of cu. ft. of gas delivered.....cu. ft.
- (a) Total weight of dry gas delivered.....lb.

(22) Moisture in gas leaving producer, mixed with 1 lb. of dry gas.....lb.
(23) Moisture of gas leaving scrubber, mixed with 1 lb. of dry gas.....lb.
(24) Equivalent cu. ft. of dry gas at temperature of 60 deg. and pressure of atmosphere of 30 in.....cu. ft.
(25) Net cu. ft. of dry gas at 60 deg. and 30 in.....cu. ft.
(26) Percentage of tar and soot in gas referred to total fuel.....per cent
(27) Total water fed to vaporizer.....lb.
- (a) Total water evaporated in vaporizer.....lb.
- (b) Total weight of steam supplied to producer.....lb.
- (c) Total weight of water fed to scrubber.....lb.

Hourly Quantities and Rates

(28) Dry coal per hour.....lb.
- (a) Dry coal per hour per sq. ft. of main fuel bed.....lb.

(29) Equivalent cu. ft. of dry gas per hour at 60 deg. and 30 in. (Item 24 ÷ Item 8).....cu. ft.

* Corrected for difference in estimated quantity of coal in producer at beginning and end of test.

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(30) Net cu. ft. of dry gas delivered per hour at 60 deg. and 30 in.....cu. ft.
(31) Water fed per hour to vaporizer.....lb.
  (*a*) Water evaporated per hour in vaporizer.....lb.
  (*b*) Steam supplied to producer per hour.....lb.
(32) Water fed to scrubber per hour.....lb.

Proximate Analysis of Coal

(33) Fixed carbon.....per cent
(34) Volatile matter.....per cent
(35) Moisture.....per cent
(36) Ash.....per cent
(37) Sulphur, separately determined.....per cent

100 per cent

Ultimate Analysis of Dry Coal

(38) Carbon (C).....per cent
(39) Hydrogen (H).....per cent
(40) Oxygen (O).....per cent
(41) Nitrogen (N).....per cent
(42) Sulphur (S).....per cent
(43) Ash.....per cent

100 per cent

Analysis of Ash and Refuse

(44) Carbon.....per cent
(45) Earthy matter.....per cent
(46) Fusing temperature of ash.....deg.
(47) Nature and texture of ash.....

Analysis of Gas by Volume

(48) Carbon dioxide (CO_2).....per cent
(49) Carbon monoxide (CO).....per cent
(50) Oxygen (O).....per cent
(51) Hydrogen (H).....per cent
(52) Marsh Gas (CH_4).....per cent
(53) Olefiant gas (C_2H_4).....per cent
  (*a*) Sulphur dioxide (SO_2).....per cent
  (*b*) Hydrogen sulphide (H_2S).....per cent
  (*c*) Nitrogen (N) by difference.....per cent

100 per cent

  (*d*) Total combustible gases.....per cent

Calorific Values by Calorimeter

(54) Calorific value of 1 lb. of dry coal.....B.t.u.
(55) Calorific value of 1 lb. of combustible.....B.t.u.
(56) Calorific value of 1 cu. ft. of dry gas at 60 deg. and 30 in. (higher value).....B.t.u.

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Economy Results

(57) Equivalent cu. ft. of dry gas at 60 deg. and 30 in. per lb. of dry coal .....cu. ft.

(a) Equivalent cu. ft. of dry gas at 60 deg. and 30 in. per lb. of combustible cu. ft.

(58) Net. cu. ft. of dry gas at 60 deg. and 30 in. per lb. of dry coal.....cu. ft.

(a) Net cu. ft. of dry gas at 60 deg. and 30 in. per lb. of combustible.....cu. ft.

Efficiency

(59) Gross efficiency of producer, based on dry coal.....per cent

(a) Net efficiency of producer, based on dry coal .....per cent

(60) Gross efficiency of producer, based on combustible.....per cent

(a) Net efficiency of producer, based on combustible.....per cent

Cost of Coal

(61) Cost of coal per ton of ———— lb. delivered.....dollars

(62) Co t of coal required for producing 1,000 net cu. ft. of gas at 60 deg. and 30 in.....dollars

(a) Cost of coal for producing 1,000,000 B.t.u.....dollars

Heat Balance Based on 1 Lb. of Dry Coal

		B.t.u.	per cent
(63)	Total calorific value of 1 lb. of dry coal, same as Item 54	.....	.....
(a)	Calorific value of dry gas	.....	.....
(b)	Sensible heat in hot dry gas above 60 deg. Fahr	.....	.....
(c)	Total heat of moisture in gas above 60 deg	.....	.....
(d)	Heat lost in scrubber	.....	.....
(e)	Heat lost by combustible in ash	.....	.....
(f)	Heat lost by radiation, and unaccounted for (difference between the sum of items *a*, *b*, *c*, *d*, *e* and Item 63)	.....	.....

Note:—If steam is supplied to the producer from an outside source the data and results should be modified accordingly.

Experiment No. 40

TWO CYCLE MARINE GAS ENGINE TEST

In all stationary internal combustion engines the speed is controlled by means of a governor. In marine work, particularly in the smaller type of engines, a governor is not necessary as the propeller attached to the engine is sufficiently large to prevent the engine from running higher than the desired speed. Without a governor on an engine it is difficult to determine the efficiency at various loads under constant speed. A much more satisfactory test on a ma-

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rine engine can be obtained by determining the maximum horsepower that the engine will deliver at different speeds.

The engine used in this experiment will be a two cylinder, two cycle, three port 6 H. P. Gray marine engine equipped with a water friction brake. The size of the cylinders are bore 3½ in.; stroke 3½ in.

The brake consists of a water wheel, with buckets on the sides, running in a housing completely filled with water. There is no frictional contact between the wheel and the housing. The load is varied by changing the opening of gates in the sides of the housing, thereby varying the ease with which the water can escape from the housing, or by varying the pressure of the water in the housing. The housing is equipped with a lever arm two feet long, which rests upon platform scales. The Prony brake formula is used for figuring brake horsepower.

Directions for Test

Wire up the engine with battery and ignition coil, start the engine and after the jacket water has reached the proper temperature, make a series of five ten minute runs at maximum load for speeds indicated by your instructor, and determine the fuel consumption.

Read over the general instructions on page 144 in connection with this experiment, and report your general data and results on forms as outlined in Experiment 32. Include in your report a wiring diagram and plot curves between speed as abscissae and horsepower, thermal efficiency, and fuel consumption per brake horsepower as ordinates.

In your preliminary report include a description with sketch of the operation of a three port, two cycle, internal combustion engine.

Experiment No. 41

TEST OF AN AIR COMPRESSOR

There are several different classes of machines which can be used to compress air. Among these are the centrifugal fan and blower, the rotary blower, the turbo-compressor, the reciprocating piston compressor and the compressor employing a stream of falling water. Some of these machines are limited as to the range of pressure through which compression is carried.

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Tests will be made in the laboratory on the Ingersoll-Sargent cross-compound air compressor. This consists of a high and low pressure steam cylinder connected to a crank shaft carrying a flywheel. The tail rods of the steam cylinders are connected to two air cylinders, one a low pressure and one a high pressure with an intercooler between them, thus forming a two stage unit.

The valve construction of the Ingersoll-Sargent compressor is very interesting. Air enters through a hollow tail rod into the center of a hollow cored piston. There are two ring shaped valves, one on each side of the piston, with a circular extension covering a turned portion of the piston. These valves cover ports on the piston face connecting to the inside of the piston. Their play is limited by a dowel fitting an oblong hole.

In operation air is drawn in through the hollow piston rod and passes through the valves first into one end of the cylinder, and then into the other. The stopping of the piston at the end of its stroke alternately opens and closes these valves by their own inertia. They have no springs connected with them. Since the valves are of large diameter and open a large port area, their lift is small. One claim for this valve is that the suction of the compressor does not have to overcome a spring on the inlet valve while the air is entering the cylinder, thus increasing the volume of free air drawn in per stroke.

The discharge valves are of the ordinary spring poppet type. The air is compressed on the lower side of these valves until the pressure becomes sufficient to overcome the tension of the spring and the air pressure above the valve, when the valve lifts and allows the air to discharge.

The arrangement of this valve gear can be seen on the blue print in the laboratory.

There is always a considerable rise in temperature in compressing air which not only increases the work in the cylinder but interferes with lubrication as well. Some compressors have ribs cast on their air cylinders which dissipate by radiation the heat of compression developed in the cylinder. This is usually the case with locomotive air pumps which are exposed to considerable draft on the locomotive.

Other compressors such as the one to be tested, are water jacketed and a cooler is provided between cylinders when the unit is built two stage. The temperature of the air supplied to the high pressure cylinder and consequently its volume, is reduced. Hence a smaller high pressure cylinder can be used than would otherwise be the case.

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Since a smaller volume of air is handled by the high pressure cylinder, less work is done in finishing compression than if no intercooler were present.

The air compressor in the laboratory delivers into a large receiver tank where the pressure and temperature are maintained practically constant. The amount of air delivered is found by discharging it from this receiver through a nozzle and calculating the weight discharged.

The steam cylinders of the air compressor in the laboratory are fitted with Meyer cut-off valve gear by means of which the point of cut-off can be altered, while the engine is in operation, by changing the position of the riding cut-off valves. The main slide valve and the riding cut-off valves are each driven by separate eccentrics.

One method of determining the discharge of an air compressor is to deliver the air alternately into either one of two tanks of known volume. The temperature at various points in the tank and also the pressure of the contained air before and after filling, are carefully determined and from this the quantity delivered to the tank with each filling, can be calculated. Each tank is provided with a large quick opening valve to discharge the compressed air into the atmosphere after the tank has been cut off from the compressor and all readings taken. This method is quite accurate if all valves are absolutely tight and if sufficient temperature observations are taken of the air in the tank. Such tanks are not always available so that nozzles are often used for measuring the discharge. The available information regarding flow of air through nozzles is not very conclusive, but pending further results, the formulae derived by Fliegner and given below, will be used with the nozzle in the laboratory.

To Calculate the Discharge of Air

1. Weight of air escaping from the nozzle per second in lbs.

$$w = 0.530\, A \frac{P_1}{\sqrt{T_1}} \text{ where } P_1 > 2\, P_a \quad \text{.....I}$$

$$\text{or } w = 1.060\, A \sqrt{\frac{P_a\,(P_1 - P_a)}{T_1}} \text{ where } P_1 < 2\, P_a \quad \text{.....II}$$

where P_1 is the pressure before the nozzle in pounds per sq. in. absolute,* P_a the barometric pressure in pounds per sq. in. absolute,

*P_a = partial air pressure given by humidity. See chapter on Humidity and Hygrometry. P_a = barometric pressure minus vapor pressure.

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T_1, the absolute temperature of the air entering the nozzle in degrees F., A the area of the orifice of the nozzle in sq. ins.

Use formula I or II according as P_1 may be greater or less than $2\,P_a$.

The results given by formula II are open to question and should experiments be made under these conditions, the student is referred to later results given in a paper on "Air Flowing into Atmosphere through Circular Orifices," by R. J. Durley, *Transactions A. S. M. E.*, Vol. 27.

2. Pounds compressed per minute

$$W_1 = 60\,w.$$

3. Volume of one pound of dry atmospheric air in cu. ft.

$$V_a = \frac{53.35\,T_a}{144\,P_a}$$

where T_a is the absolute temperature of the room in degrees F. When the humidity is known, the volume of one pound of air can be found as indicated in the chapter on Hygrometry.

4. Vol. compressed per second.

$$\text{Weight of 1 cu. ft. dry air} = \frac{1}{V_a} = \ldots\ldots\ldots\

Let V_c = clearance volume at discharge pressure P_1, and V_2 = any volume near admission measured from the end of the stroke and at a pressure P_2 on the actual card.

Then $P_1 V_c^n = P_2 (V_c + V_2)^n$

from which V_c can be easily found.

Expressions of Efficiency for an Air Compressor

The efficiencies of piston air compressors have been expressed by different authors in a number of ways. The Department of Steam and Gas Engineering has adopted the following definitions of the various efficiencies of this type of machine:

$$\text{Cylinder efficiency} = \frac{\text{Work done in a complete cycle to compress isothermally a volume of air at atmospheric pressure equal to L. P. piston displacement}}{\text{Actual work done in air cylinders}}$$

$$= \frac{\text{Efficiency of compression}}{\text{Volumetric efficiency}}$$

$$\text{Volumetric efficiency} = \frac{\text{Vol. of free air drawn in}}{\text{L. P. piston displacement}}$$

$$\text{Efficiency of compression} = \text{Cylinder efficiency} \times \text{volumetric efficiency}$$

$$= \frac{\text{Work done in a complete cycle to compress isothermally the given vol. of air from atmospheric to final pressure}}{\text{Work actually expended in compressing the same volume}}$$

$$\text{Mechanical efficiency} = \frac{\text{H. P. of air cylinders}}{\text{H. P. of steam cylinders}}$$

$$\text{Net efficiency of compressor system} = \frac{\text{Energy available from adiabatic expansion of the saturated compressed air at room temperature to atmospheric pressure}}{\text{H. P. of steam cylinders}}$$

Conduct of Test

Place indicators on both steam and both air cylinders. Note the reducing motion for these indicators and include a sketch of same in your report.

See that the valves are open to the receiver and to the nozzle.

Run the engine for 1 hour previous to taking data, in order that the engine cylinders, jacket water, etc., come to a constant temperature.

Run a one hour test with such constant air pressure in the receiver as the instructor may specify.

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Plot a combined card for the high and low pressure air cylinders. From the point where the compression line crosses the atmospheric line draw an isothermal curve to the discharge line. From the same point also draw an adiabatic line by plotting several points from the formula $P V^{1.4} = a$ constant. Calculate from your combined cards the value for n in the formula $P V^n = C$ for compression in each of the water cooled cylinders of the compressor. Note the effect of the intercooler.

Calculate the various efficiencies connected with the air compressor as previously defined; also calculate the efficiency of the intercooler.

From the combined cards, calculate the power that would have been required to compress this air adiabatically without cylinder cooling or the use of an intercooler.

Report the test on the following forms:

Form No. 1. FORM OF LOGS

Test of.....AIR COMPRESSOR

Made at..... Date.....

Barometer..... Observers.....

Time	Continuous counter	r.p.m.	PRESSURES								Temperature in calorimeter	Weight of condensed steam	Weight of jacket water	Weight of condenser cooling water
			Steam line	Receiver	Condenser	Air entering L. P. cyl.	Intercooler	Reservoir	Before nozzle	Back pres. in calorimeter				

Form No. 2. TEST OF.....AIR COMPRESSOR

Made at..... Date.....

Barometer..... Observers.....

Time	TEMPERATURE OF AIR							TEMPERATURE OF WATER					
	Wet bulb	Dry bulb	External air	Air entering L. P. cyl.	Air leaving L. P. cyl.	Air entering H. P. cyl.	Air leaving H. P. cyl.	Air on pres. side of nozzle	Entering intercooler	Leaving intercooler	Leaving H. P. cyl. jacket	Leaving L. P. cyl. jacket	Entering condenser	Leaving condenser

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Dimensions. Air Comp.	Steam H. P.	Steam L. P.	Air H. P.	Air L. P.
Diam. Cylinders	12″	20″	12.5 ″	18.25″
Piston Rod Diam. H. E.	2″	2″	2.75″	4⅜ ″
C. E.	2″	2″	2 ″	2 ″
	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.
Piston Displacement H. E.	.7638	2.16	.7772	1.712
C. E.	.7638	2.16	.797	1.795

Stroke 12″
H. P. Springs Air 60 lb. Steam 80 lb.
L. P. Springs Air 20 lb. Steam 20 lb.
Diameter of Nozzle ⅜″

Form No. 3. Test of ..... Air Compressor
Test made at ..... Date .....
Barometer ..... Observers .....

Horsepower—Steam Cylinders	High.	Low.
Diameter of piston in		
Area of piston, sq. in.		
Diameter of piston rod, in., head		
crank		
Area of piston rod, sq. in., head		
crank		
Length of stroke, ft.		
Spring of indicator lb.		

Time	r.p.m.	High Pressure					Low Pressure					
		Head		Crank		Total i.h.p.	Head		Crank		Total i.h.p.	Net i.h.p.
		m.e.p.	i.h.p.	m.e.p.	i.h.p.		m.e.p.	i.h.p.	m.e.p.	i.h.p.		

Form No. 4. Test of ..... Air Compressor
Test made at ..... Date .....
Barometer ..... Observers .....

Horsepower—Air Cylinders	High	Low
Diameter of pistons, in.		
Area of pistons, sq. in.		
Diameter of piston rods, in., head		
crank		
Area of piston rods, sq. in., head		
crank		
Length of stroke, ft.		
Spring of indicator, lb.		

Time	r.p.m.	Low Pressure					High Pressure					
		Head		Crank		Total i.h.p.	Head		Crank		Total i.h.p.	Net i.h.p.
		m.e.p.	i.h.p.	m.e.p.	i.h.p.		m.e.p.	i.h.p.	m.e.p.	i.h.p.		

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CALCULATION OF RESULTS [1]

103 The rules pertaining to dry steam, heat consumption, and indicated horsepower of the steam end, are identically the same as in the Steam Engine Test, and reference may be made to that test for the necessary directions in these particulars.

103a Air Horsepower

The gross work done at the air end of a reciprocating machine, expressed in horsepower, is found by multiplying together the net area of the air piston in sq. in., the mean effective air pressure in lb. per sq. in. as determined from indicator diagrams, the length of the stroke in ft., and the number of single strokes per minute, and dividing their product by 33,000.

The net work at the air end of either reciprocating or rotary machines, expressed in ft-lb. per minute, is found by multiplying the corrected volume of the compressed air in cu. ft. delivered into the main delivery pipe per minute, by the impact or total pressure in lb. per sq. ft. and by the hyperbolic logarithm of the ratio of the total pressure to the atmospheric pressure (all pressures being absolute pressures). The net air horsepower is found by dividing the product by 33,000. The corrected volume of the compressed air may be found by multiplying the sectional area of the delivery main in sq. ft. by the mean velocity in ft. per minute as determined by Pitot tube or other measurement, and reducing the result to atmospheric temperature by multiplying by the proportion.

$$\frac{460+T_1}{460+T_2}$$

in which T_1 is the temperature of the air supplied to the machine and T_2 the temperature of the air in the delivery main.

103b Capacity

The capacity is the number of cu. ft. of air discharged through the delivery main per minute, as determined by gasometer, tank, or other mode of measurement, reduced to the equivalent free air at the atmospheric temperature and pressure. The correction for pressure is made by multiplying by the proportion $\frac{P_2}{P_1}$, in which P_1 is the atmospheric pressure and P_2 the total pressure in the main (absolute pressures), while the correction for temperature is determined as above stated.

The capacity may also be expressed in the number of cu. ft. of compressed air delivered per minute at a given pressure above the atmosphere reduced to the atmospheric temperature.

103c Miscellaneous

For methods of calculating results pertaining especially to the performance of the steam-end of a reciprocating air pumping machine, reference may be made to the Steam Engine Code, ¶ 77.

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[1] In the case of air machinery driven by some other prime mover than a steam engine or turbine, the code may be modified to meet the particular requirements.

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The "efficiency of compression" in a reciprocating machine is determined by first ascertaining the net work at the air end given above under the heading, "103a Air Horsepower," and dividing the net work thus found by the gross work given under the same heading.

The "mechanical efficiency" of a reciprocating machine is determined by dividing the gross air horsepower at the air end by the indicated horsepower at the steam end, or by the horsepower delivered by the belt or motor in the case of other means of driving.

DATA AND RESULTS

104 The data and results should be reported in accordance with the form (Table 14) given herewith, adding lines for data not provided for and omitting those not required, as may conform with the object in view. If a shorter form is desired, the items in fine print designated by letters of the alphabet may be omitted. Unless otherwise indicated the items should be the averages of the data.

105 In the case of an air-pumping machine of the reciprocating class for which a record of the complete performance is desired, the additional engine data and results given in the Steam Engine Code may supplement those here given:

TABLE 14 DATA AND RESULTS OF TEST OF COMPRESSORS, BLOWERS, OR FANS

Code of 1915

(1) Test of.....located at.....
To determine.....
Test conducted by.....

DIMENSIONS, ETC.

(2) Type of machinery.....
(3) Rated capacity in cu. ft. of free air per minute.....cu. ft.
(*a*) Rated capacity in cu. ft. of air discharged per minute at 100 lb. pressure, reduced to 62 degrees.....cu. ft.
(*b*) Name of builder.....
(4) Size of engine or turbine (see Engine and Turbine Codes).....
(5) Size of air cylinders or blowers.....
(6) Auxiliaries (steam or electric driven).....
(*a*) Type and make of condenser equipment.....
(*b*) Rated capacity of condenser equipment.....
(*c*) Type of oil pump, jacket pump, and reheater pump (direct or independently driven).....

DATE AND DURATION

(7) Date.....
(8) Duration.....hr.

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Average Pressures and Temperatures

(9) Pressure in steam pipe near throttle, by gage.....lb. per sq. in.
(10) Barometric pressure.....in. of mercury
  (a) Steam chest pressure.....lb. per sq. in.
  (b) Pressure in receivers, by gage.....lb. per sq. in.
  (c) Pressure in turbine stages, by gage.....lb. per sq. in.

(11) Pressure in exhaust pipe near engine or turbine, by gage.....lb. per sq. in.
(12) Vacuum in condenser.....in. of mercury
  (a) Corresponding absolute pressure.....lb. per sq. in.
  (b) Absolute pressure in exhaust chamber.....lb. per sq. in.

(13) Temperature of steam, if superheated, at throttle.....deg.
  (a) Normal temperature of saturated steam at throttle pressure.....deg.
  (b) Temperature of steam leaving receivers, if superheated.....deg.

(14) Temperature of steam in exhaust pipe near engine or turbine.....deg.
  (a) Temperature of circulating water entering condenser.....deg.
  (b) Temperature of circulating water leaving condenser.....deg.

(15) Temperature of air in delivery main*.....deg.
  (a) Temperature of air supplied to machine.....deg.
  (b) Temperature by wet bulb thermometer.....deg.
  (c) Relative humidity.....deg.

(16) Pressure in delivery main by gage (impact pressure)*.....lb. per sq. in.
  (a) Pressure in each stage, if more than one.....lb. per sq. in.

Quality of Steam

(17) Percentage of moisture in steam near throttle, or number of degrees of superheating.....per cent or deg.

Total Quantities

(18) Total water fed to boilers..... lb.
(19) Total condensed steam from surface condenser (corrected for condenser leakage).....lb.
(20) Total dry steam consumed (Items 18 or 19 less moisture in steam).....lb.
(21) Total volume of compressed air delivered, as measured.....cu. ft.
  (a) Total volume of compressed air delivered, reduced to atmospheric temperature and pressure.....cu. ft.
  (b) Total weight of air delivered.....lb.

Hourly Quantities

(22) Total water fed to boilers, or drawn from surface condenser, per hour.....lb.
(23) Total dry steam consumed for all purposes (Item 20 ÷ Item 8).....lb.
(24) Steam consumed per hour for all purposes foreign to main engine.....lb.

* In the case of compressors or blowers having more than one stage, additional data should be given covering pressures and temperatures in the different stages, the quantity of water used for cooling, and temperatures of the air and water entering and leaving the intercooler.

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(25) Dry steam consumed by engine or turbine per hour (Item 23 — Item 24).....lb.

(a) Circulating water supplied to condenser per hour.....lb.

(26) Volume of compressed air delivered per hour, as measured.....cu. ft.

(a) Volume of compressed air delivered per hour, reduced to atmospheric temperature.....cu. ft.

(b) Volume of compressed air delivered per hour, reduced to atmospheric temperature and pressure.....cu. ft.

(c) Weight of air delivered per hour.....lb.

Hourly Heat Data

(27) Heat units consumed by engine or turbine per hour (Item 25 multiplied by total heat of 1 lb. of steam at pressure of Item 9, less heat in 1 lb. of water at temperature of Item 14).....B.t.u.

Indicator Diagrams

1st. cyl. 2d cyl.

(28) Mean effective pressure, each steam cylinder....lb. per sq. in.....

(a) Mean effective pressure, each air cylinder.....lb. per sq. in. .....

Speed

(29) Revolutions per minute.....r.p.m.

(a) Number of single strokes per minute.....strokes

Power

(30) Indicated horsepower of steam end.....i.h.p.

(31) Gross air horsepower as indicated in air cylinders.....h.p.

(a) Brake horsepower consumed by blower or fan.....br.h.p.

(32) Net air horsepower (see ¶ 103a).....h.p.

(33) Friction horsepower (Item 30 — Item 31).....h.p.

(34) Percentage of i.h.p. lost in friction of machine.....per cent

Capacity

(35) Compressed air delivered per minute as measured.....cu. ft.

(a) Compressed air delivered per minute, reduced to atmospheric temperature.....cu. ft.

(b) Compressed air delivered per minute at 100 lb. pressure, reduced to 62 degrees.....cu. ft.

(36) Compressed air delivered per minute, reduced to atmospheric temperature and pressure (free air).....cu. ft.

Economy Results

(37) Heat units consumed per i.h.p-hr.....B.t.u.

(38) Heat units consumed per net h.p-hr. of Item 32.....B.t.u.

(39) Dry steam consumed per i.h.p-hr.....lb.

(40) Dry steam consumed per net air h.p-hr. of Item 32.....lb.

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Efficiency Results

(41) Thermal efficiency referred to i.h.p. [(2546.5 ÷ Item 37) × 100].....per cent
(42) Thermal efficiency referred to net air h.p. [(2546.5 ÷ Item 38) × 100]
.....per cent
(43) Efficiency of compression [(Item 32 ÷ Item 31) × 100].....per cent
(*a*) Mechanical efficiency of machine [(Item 31 ÷ Item 30) ×100].....per cent
(*b*) Volumetric efficiency [(Item 36 ÷ displacement in cu. ft. per minute of first compressor) ×100].....per cent

Work Done per Heat Unit

(44) Net work per B.t.u. (1,980,000 ÷ Item 38).....ft-lb.

Sample Diagrams

(45) Sample indicator diagrams from each cylinder.....

Heat Distribution B.t.u.

46. Heat to compress volume of item 36 adiabatically from inlet to discharge absolute pressure.....
47. Heat in work from air horsepower.....
48. Heat absorbed by jacket water
    a. From intercooler.....
    b. From h. p. jacket.....
    c. From l. p. jacket.....
49. Heat dispersed in radiation.....

Note:—The items relating to indicator diagrams and indicated horsepower are to be used only in cases where the machine is of the reciprocating type.

Experiment No. 42

THE MEASUREMENT OF GASES

Gases may be measured by means of volumetric meters or by velocity meters.

Volumetric meters include what are known as dry meters operating on the general principle of a bellows and used largely as house meters, and wet meters, which are installed in large sizes in gas works. Descriptions of these instruments and methods of testing will not be discussed in this text.

Gas holders are also sometimes used for the measurement of gases. Small sized gas holders are often used to check the readings of volumetric meters.

The experimental work in the laboratory will deal largely with velocity meters. The simplest form is the anemometer, which con-

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sists of a small fan mounted on pin bearings and provided with a dial registering mechanism to record its revolutions. The instrument is placed in the current of gas with its axis parallel to the flow and the speed per minute is noted. The dial mechanism can be started or stopped by a trip on the top of the casing. The instrument needs calibration to determine the actual velocities corresponding to certain readings of the dial. This can be done by mounting the anemometer on the end of a long horizontal arm and revolving this arm in a room of still air about a vertical axis at a constant

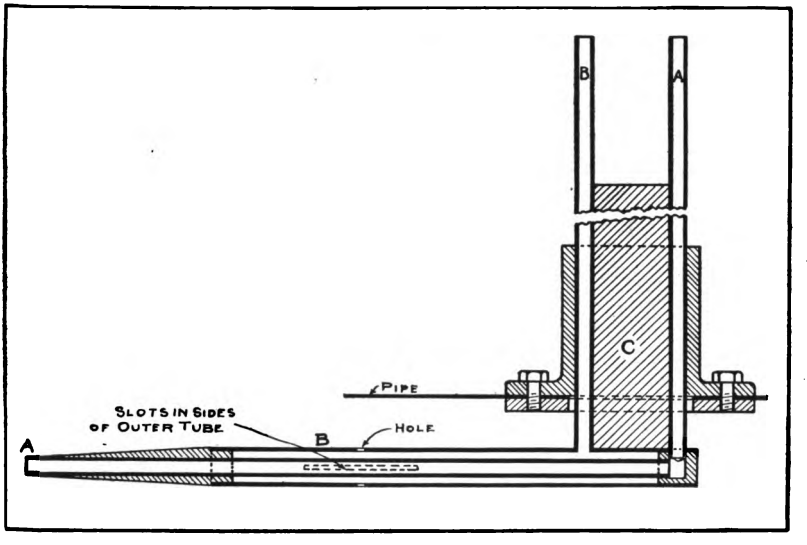

FIG. 28. PITOT TUBE FOR AIR

speed. The axis of the anemometer must be at right angles to the axis of the arm. The distance through which the anemometer moves can be computed and the record of the dial checked.

Another method is to place the anemometer in a pipe through which air is flowing at a known velocity and again check the dial readings.

THE PITOT TUBE

Gases can be measured by means of Pitot tubes. One of these instruments used in the laboratory is shown in Fig. 28. The opening at A points upstream and communicates, through the tube A, the pressure and velocity head of the gas, while two small holes and

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two slots as shown, opening at right angles to the direction of flow, communicate the pressure head alone through the tube B. The pressure head alone is measured and the difference in pressure of the tubes A and B must be measured very accurately. This latter represents the velocity head. The temperature of the gas at the point where the Pitot tube is inserted should also be measured.

When this tube is used in a circular pipe, the shank C, of which the pressure tube forms a part, passes through a bushing to the outside of the pipe, making it possible to slide the tube to any point between the center of the pipe and its outside surface. The position of the Pitot tube with respect to the center of the pipe can be read at any time by measuring from some marked point on the shank C.

The velocity head should be determined at intervals across the whole section of the pipe.

The mean value of the velocity head can be calculated by the method given in *Notes on Hydraulic Instruments* by Professor G. J. Davis.

When the velocity head is known, the velocity v of the gas in the pipe in feet per second can be determined from the formula

$$v = C\sqrt{2gH}$$

where H is the velocity head in feet of the gas and C is an experimentally determined constant.

If water is used as the manometer liquid let h equal the velocity head in inches of water and r equal the number of feet of gas which will give the same pressure as 1 in. of water.

Then

$$v = C\sqrt{2ghr}$$

The constant C will be supplied to the students at the time of the tests, but should vary only slightly from unity with the above instrument.

The cubic feet of gas passing through the pipe per second is given by the formula.

$$Q = A\,v$$

where A = area of pipe in sq. ft.

v = velocity in feet per second.

The weight G of a cubic foot of gas should be determined. If moisture is present, it must be allowed for in calculating G.

Then the pounds of gas per hour passing through the pipe is

$$W = 3600\,G\,A\,v$$

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If air is the gas measured, then the weight per cubic foot of air may be found as outlined in the chapter on Hygrometry.

The Venturi Meter

The Venturi meter has recently been applied successfully to the measurement of gases. It consists of a throat, or gradually contracted portion of the passage, which causes a decrease in pressure and an increase in the velocity of the gas flowing through it. The pressure on the upstream side and the pressure at the throat must be measured carefully. The temperature of the up-stream section must also be determined. The barometer must be read at frequent intervals.

The weight of gas passing through per second can be determined as follows:

Let A_1 = area on the up-stream side, in sq. ft.
A_2 = area of throat, in sq. ft.
P_1 = absolute pressure at the up-stream side, in lbs. per sq.ft.
P_2 = absolute pressure at the throat, in lb. per sq. ft.
G_1 = weight of 1 cu. ft. of gas at upstream side, in lb.
n = ratio of specific heats of the gas at constant pressure and constant volume.
v_2 = velocity of the gas at the throat in feet per second.

By equating the loss in potential energy to the increase in kinetic energy, the velocity at the throat is found as

$$v_2 = C_2 \left(\frac{P_1}{G_1}\right)^{\frac{1}{2}} \left(\frac{2gn}{n-1}\right)^{\frac{1}{2}} \left\{\frac{1-\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}}{1-\left(\frac{A_2}{A_1}\right)^2 \left(\frac{P_2}{P_1}\right)^{\frac{2}{n}}}\right\}^{\frac{1}{2}}$$

where C_2 is an experimentally determined coefficient.

The weight of gas flowing per hour through the pipe is

$$W = 3600\, C_2\, A_2\, v_2\, G_1 \left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}$$

$$= 3600\, C_2\, A_2 \cdot (P_1 G_1)^{\frac{1}{2}} \cdot \left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} \cdot \left(\frac{2gn}{n-1}\right)^{\frac{1}{2}} \cdot \left\{\frac{1-\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}}{1-\left(\frac{A_2}{A_1}\right)^2 \cdot \left(\frac{P_2}{P_1}\right)^{\frac{2}{n}}}\right\}^{\frac{1}{2}}$$

With a given gas $3600\, A_2 \cdot \left(\frac{2gn}{n-1}\right)^{\frac{1}{2}}$ becomes a constant K and the formula becomes

$$W = K\, C_2\, (P_1 G_1)^{\frac{1}{2}} \cdot \left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} \cdot \left\{\frac{1-\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}}{1-\left(\frac{A_2}{A_1}\right)^2 \cdot \left(\frac{P_2}{P_1}\right)^{\frac{2}{n}}}\right\}^{\frac{1}{2}}$$

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When air is being measured the density or weight per cu. ft., G_1, can be found as shown in the chapter on Hygrometry. n for air equals 1.406 and the constant K becomes

$$K = 53755.9\, A_2$$

Blueprints of curves for use in this computation and giving values of $\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}$, $\left(\frac{P_2}{P_1}\right)^{\frac{2}{n}}$ and $\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$, can be obtained in the laboratory.

The complete theory of the Venturi meter for air can be found in E. P. Coleman's paper, "The Flow of Fluids in a Venturi Tube," Vol. 28., *Transactions A. S. M. E.*, also T. R. Weymouth, "Measurement of Natural Gas." *Transactions A. S. M. E.* Vol. 34, Page 1639, to which the student is referred.

If occasion should arise where the Venturi meter is used continuously for any gas of constant composition, the above formula can be plotted in the form of a single curve and the flow determined from this chart.

The Thomas Electric Meter

Gases can also be measured by the Thomas electric meter, which is based on the principle of heating air or gas through a known range of temperature and measuring the energy required to cause the change in temperature. This measured energy is proportional to the weight of gas flowing. Electric energy is used as the source of heat as it can be accurately measured. The temperature range is regulated by the use of electrical resistance thermometers.

Then if E is the amount of energy, in watts, supplied to raise the temperature of W pounds of gas per hr. through t degrees F., and if s is the specific heat at constant pressure of a unit weight of the gas, then

$$W = \frac{3.412\, E}{t\, s}.$$

The electric meter used in the laboratory is shown diagrammatically in Fig. 30. An electric heater H is placed within a casing between two electric resistance thermometers T_1 and T_2. The heater consists of spiral turns of bare nichrome resistance wire wound around a conical frame and supported by insulators so that heat is dissipated evenly over the section of the pipe. A rheostat is placed in the heater circuit for regulating the direct current supplied. This energy is measured by an ammeter and voltmeter.

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The thermometers consist of resistance wire wound on wooden spindles and evenly distributed over the section of the casing. The wire is of such material that its resistance increases with the temperature according to known laws. The two thermometers form two arms of a Wheatstone bridge, the other two arms being fixed coils of wire that have a zero temperature coefficient. A galvanometer is connected across the Wheatstone bridge and a small rheostat is placed in series with one thermometer for balancing the bridge when no heat is passing through the heater. A small resistance R_T is arranged so that it can be placed in or out of series with the entrance thermometer. This resistance is equal in value to the increase in the resistance of the exit thermometer for a known rise in temperature.

In the later development of the design of this meter, the heater element is made up of a series of small diameter bare spiral coils placed parallel and in the same plane across the diameter of the heater instead of the cone as above, and so supported as to be entirely in the stream of air or gas being measured. The thermometer elements, instead of being wound on wooden spindles, are mounted with the equivalent length of wire, arranged in groups of about six strands to a group, carefully insulated and armored, the various units being placed parallel about an inch apart and in the same plane. This new arrangement is more sensitive and therefore more accurate than the old arrangement, and does not offer such large resistance to the flow of air.

The operation of the meter is as follows: With gas flowing through the meter but with no energy in the heater, and with R_T out of circuit, the two thermometers are brought to the same balance by means of the balancing rheostat and the galvanometer. Then the resistance R_T is put in circuit and sufficient electrical energy is supplied to the heater to balance the galvanometer. The measuring instruments in the heater circuit then indicate the energy required to raise the temperature of the air or gas through a known range. The quantity of gas flowing can be found by the previous equation. If the volume of the gas is required, its pressure, temperature, and relative humidity must also be found and calculations made as in the chapter on Hygrometry.

$$\text{Cu. Ft. of Air per Min.} = K. \frac{(\text{Volts})\ (\text{Amperes})}{(\text{Sp. Ht.})\ (\text{Wt. per Cu. Ft.})}$$

Where $K = .02047\ C$

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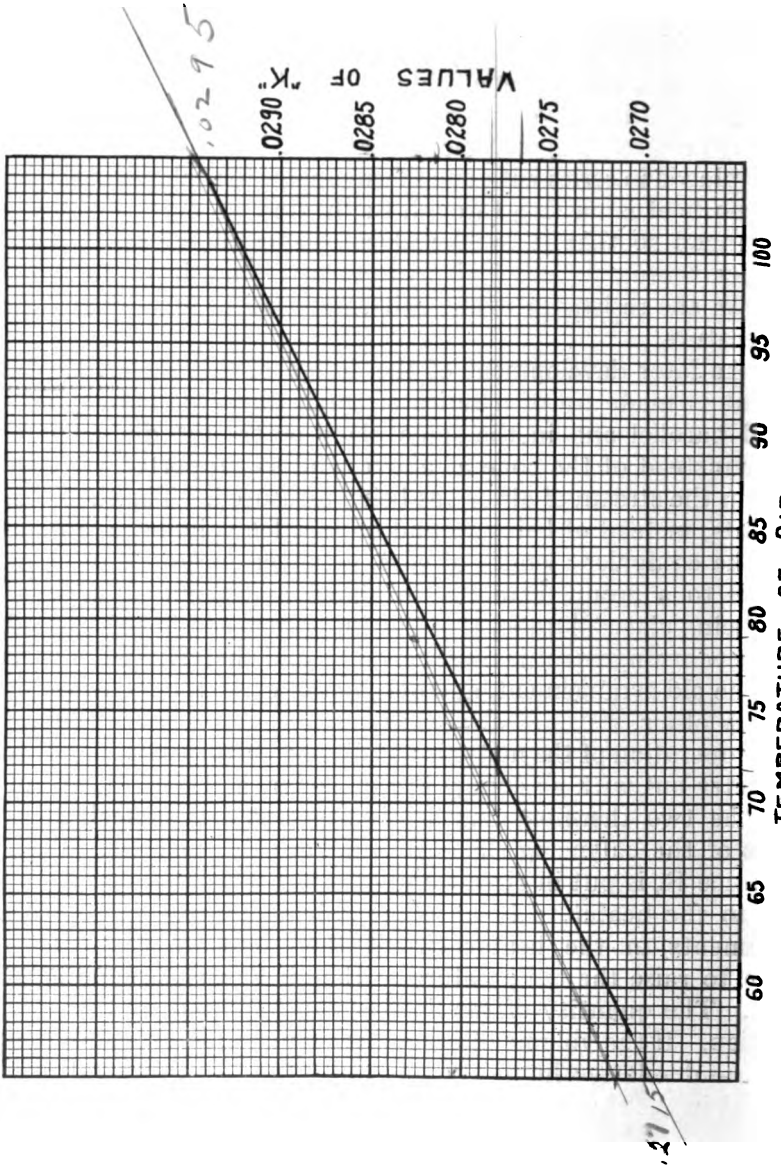

FIG. 29. "K" CURVE FOR THOMAS METER

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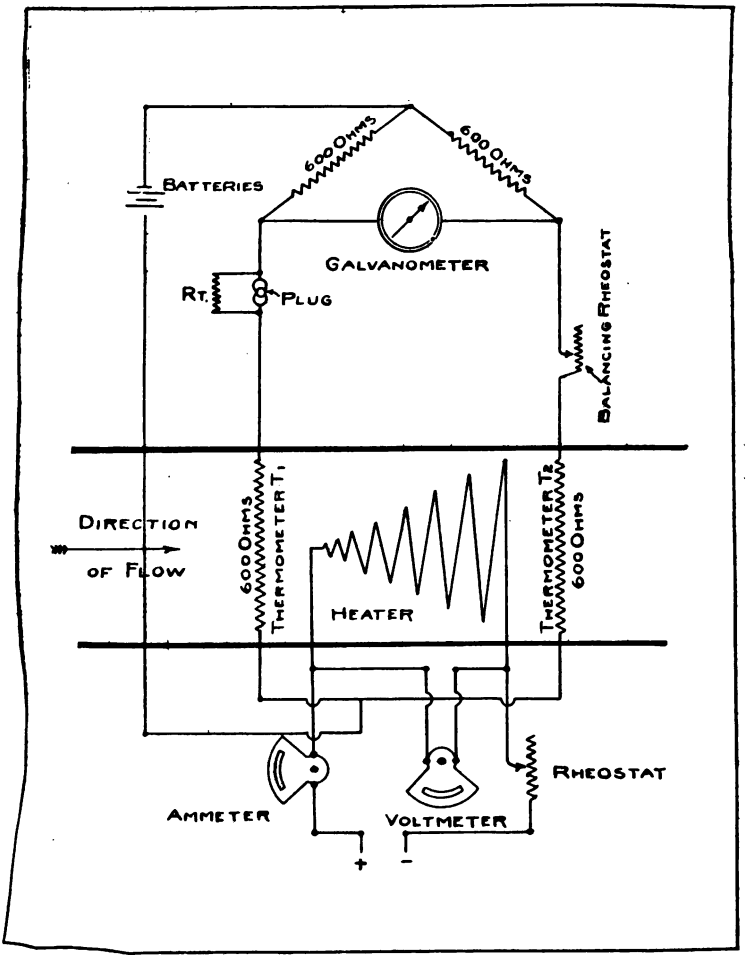

FIG. 30. DIAGRAM OF THOMAS ELECTRIC GAS METER

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C is the increase in resistance in the meter thermometers per degree rise in temperature in °F.

Values of K at ordinary temperatures are plotted in Fig. 29.

TESTS

Tests will be made in the laboratory to measure air flow, in which each of the instruments just described will be employed. The students will prepare the necessary forms for recording the data at the time of the tests and will make their reports according to the requirements of the given test.

Plot curves of r.p.m. of fan vs. items No. 17 and No. 22, using 1 inch = 500 cu. ft. of air on the ordinate and 1 inch = 100 r.p.m. of fan on the abscissa. Also plot vertical and horizontal traverses with positions of tube on the diameter as ordinates and velocity heads as abscissae.

BAROMETER DATE

Speed	Heater		Humidity			Position	Pitot Tube							
							Vertical				Horizontal			
	Amps.	Volts	Wet bulb	Dry bulb	% Humidity		Static piez.	Velocity head piez.	Velocity head pitot	$\sqrt{H}$	Static piez.	Velocity head piez.	Velocity head pitot	$\sqrt{H}$

GENERAL DATA AND RESULTS

1. No. of run
2. R.p.m. of fan
3. Barometer in in. Hg.
4. Static in in. Hg.
5. Total press. in in. Hg.
6. Total press. in lbs. sq. in.
7. Dry bulb temp.
7. Wet bulb temp.
9. Diff. in temp.
10. Relative humidity in %
11. Specific heat of air and vapor mixture
12. Weight of mixture per cu. ft.
13. Volts to Thomas Meter
14. Amperes to Thomas Meter
15. Watts to Thomas Meter

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16. "K"
17. Cu. ft. of air by Thomas Meter
18. Velocity head in in. of gasoline at center of pipe
19. Ave. vel. head in in. of gasoline
20. Ave. vel. head in feet of air
21. Ave. vel. of air in ft. min.
22. Cu. ft. of air by Pitot Tube
23. Ratio, No. 17 to No. 22
24. Ratio, No. 19 to No. 18

Experiment No. 43

TEST OF A FAN

Note: Read Experiment 41 in connection with Experiment 43.

Fans and blowers are forms of air compressors where the air is compressed through a very small range of absolute pressures. A fan not only, as a rule, discharges air against a static pressure but also imparts velocity to the air at the same time. Hence the total head against which the fan works, is the head due to static pressure together with the equivalent head due to the velocity of discharge.

As no attempt is usually made to remove the heat generated by compression, ideal conditions would exist if the air were compressed adiabatically and discharged against the total head referred to above.

Hence for a fan the efficiency of compression may be defined

$$\text{Efficiency of compression} = \frac{\text{Work done in a complete cycle to compress adiabatically, without clearance, the given volume of air against the total head.}}{\text{Work actually expended in compressing the same volume}}$$

The mechanical efficiency of a fan is defined as

$$\text{Mechanical efficiency} = \frac{\text{Air horsepower}}{\text{Horsepower supplied to fan}}$$

$$= \frac{\text{Weight of air moved per min.} \times \text{total head}}{\text{Horsepower supplied to fan.}}$$

The theoretical head produced by a centrifugal fan may be expressed by

$$H = \frac{\mu_2 (\mu_2 + W_2 \cos \alpha_2)}{g} \text{ ft.}$$

where μ_2 = linear velocity in feet per second of the fan blade at the tip (exit).

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w_2 = the relative velocity in feet per second of the air leaving the fan wheel. (= the volume Q of air flowing in cu. ft. per sec. divided by the peripheral area of the fan wheel in sq. ft. around the exit circumference.)

α_2 = the angle made by μ_2 (drawn perpendicular to the radius from the center of the wheel) and w_2 (drawn tangent to the last blade element).

The manometric efficiency is the ratio of the gross head produced by the fan to the theoretical head, or

$$\text{Manometric efficiency} = \frac{\text{Actual total head}}{\text{Theoretical head}}$$

In running a test on a fan, it is, therefore, necessary to measure accurately the static discharge head and the velocity head. The velocity can be measured by one of the methods given in the chapter on "Measurement of Gases." When the mean velocity of discharge is known the equivalent head may be calculated from the formula

$$h = \frac{v^2}{2g}$$

where h is head and v mean velocity over section. Sometimes a fan is discharged into a chamber so large in proportion to the volume of air passing through, that the velocity becomes practically zero. Then the kinetic energy of the air will be changed into pressure head. The pressure of this chamber would, therefore, equal the sum of the static and velocity heads of the fan. The power input to the fan has to be determined by measuring the power of the engine or motor driving it. The necessary data for the manometric efficiency can be computed from the dimensions of the fan itself.

Experiments have shown that the following laws are approximately true for any given centrifugal fan.

(1) The volume of air discharged varies directly as the speed of the fan.

(2) The pressure varies as the square of the speed.

(3) The power varies as the cube of the speed.

Tests

The ventilating fan for the Engineering building is available for test. The fan is driven by a steam engine with cylinders 8 in. x 10 in. and $1\frac{5}{16}$ in. piston rod. Its discharge duct is 4 ft.-0 in. x 5 ft.-0 in. and divided off into 6 in. squares by stretched piano wire. A reduc-

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ing motion can be fitted on the engine and its i.h.p. determined. The difference in pressure between the outside air and the plenum must be measured accurately, for the fan not only forces air through the ventilating ducts but it draws it through the intake passage and heating coils as well. The velocity of discharge can be determined by an anemometer or by Pitot tubes. The speed of the fan should also be taken.

The power input to the fan can be found by multiplying the i.h.p. by the engine efficiency which must be assumed from previous data on an engine of this size and type.

The outside diameter of the fan blades is 7 ft. 3 in. while the inside diameter is 4 ft. 2 in. The width of the fan blades is 3 ft. 10 in.

The temperature, static pressure, and humidity of the air in the plenum must be measured and the weight of a cubic foot of air determined from the observations.

Run the fan at a number of speeds and determine the various efficiencies at these speeds.

Plot curves with speed as abscissae and efficiency of compression, mechanical efficiency, and manometric efficiency as ordinates. Also plot a set of curves to determine whether the three laws for centrifugal fans apply to the unit under test.

Test of Motor Driven Fan

There is usually a motor driven fan in the laboratory available for test. The output can be arranged to be measured by a Venturi meter as well as by other means. The power input can be found by measuring the power to the motor and finding its efficiencies at various speeds.

Similar tests should be run as outlined for the ventilating fan and similar sets of curves plotted.

HYGROMETRY

Hygrometry is the measurement of the amount of water vapor in the atmosphere. There is always more or less water vapor in the atmosphere depending on its temperature and its degree of saturation. The study of hygrometry is of increasing importance. It has been found by experience that the moisture in the air has a very marked effect on many industrial processes such as the spinning of cotton, the smelting of iron in blast furnaces and the ventilation of factories.

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It is also necessary to know the amount of moisture present in all measurements of air or gases and in tests of machinery for handling the same. The following notes are presented to give the student information regarding the measurements and calculations involved in hygrometry.

According to Dalton's law, when a mixture of two gases fills a space say of 1 cu. ft. the pressure in the space is the sum of the two pressures that would be produced by a cu. ft. of each of the gases alone at the same temperature. In the same manner a mixture of air and vapor has a pressure which is the sum of the pressure of an equal volume of dry air, and of vapor alone, each at the given temperature of the mixture. Air and vapor occur in mixtures varying from practically dry air to a state of saturation such that any addition to the mixture of vapor at the same temperature causes a portion to condense. To every temperature there corresponds a certain water vapor pressure or partial pressure which may be found in steam tables such as Goodenough's "Marks & Davis', " or "Peabody's."

Air in actual practice rarely contains vapor with 100 per cent saturation and the weight of water vapor present is less than the maximum for that temperature of air. The vapor is then said to be only partly saturated and the degree of saturation is expressed by the ratio of the weight of water vapor actually contained in a given space to the maximum weight that the space can contain under the conditions of absolute pressures and absolute temperatures existing at the time. This ratio is known as the "Relative Humidity." The absolute humidity is the weight of water vapor that one cu. ft. actually contains under the given pressure and temperature conditions.

Relative humidity is usually determined by means of psychrometers or wet and dry bulb thermometers. These consist of two thermometers fastened to a frame. The bulb of one thermometer is covered with cotton wick and is kept thoroughly wet with water at room temperature. If the water vapor in the air is not saturated evaporation will take place from the wet bulb and its temperature will be lowered by the abstraction of the latent heat of the water. This lowering of temperature has been found to be a measure of the relative humidity.

Psychrometers are made in two types, stationary and sling. In the sling psychrometer the wick is moistened and the whole frame whirled round by a handle for 15 to 20 seconds. The wet bulb thermometer is read immediately after stopping. The relative and abso-

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lute humidities can be obtained from the readings of the wet and dry thermometers by use of tables such as are given in Kent's *Mechanical Engineer's Pocket Book* or by charts that will be available in the laboratory.

Humidity in Engineering Problems

Suppose the barometer reads 29.214 in. at a temperature of 78° F. This corresponds to a pressure of 14.2926 lb. per sq. in. If the water vapor is saturated its partial pressure at 78° F. from the Marks and Davis steam tables is 0.4735 lb. per sq. in. The pressure of the dry air present would then be the difference of these pressures or

$$P_{air} = 14.2926 - 0.4735$$
$$= 13.8191 \text{ lb. per sq. in.}$$

Suppose, however, that the psychrometer showed a relative humidity of only 40%. From the definition of relative humidity, the vapor pressures at the same temperature are proportional to the absolute weights.

Hence with 40% humidity the vapor pressure becomes

$$0.4735 \times .4 = 0.1894 \text{ lb. per sq. in.}$$

and in this case the pressure due to the dry air present becomes

$$P_1 = 14.2926 - 0.1894$$
$$= 14.1032 \text{ lb. per sq. in.}$$

If it is necessary to find the weight of a cubic foot of such moist air, this can be found by adding the weight of the cu. ft. of dry air at its pressure and temperature to the weight of the vapor present.

The weight of the vapor present is found by multiplying the weight of a cu. ft. of vapor at the given temperature by the relative humidity. In the preceding example with 40 per cent humidity, Marks & Davis' steam tables gives the density or weight in lb. per cu. ft. at 78° F. as 0.001477.

Hence the weight of vapor present per cu. ft.

$$W_v = 0.001477 \times 0.4$$
$$= 0.000591 \text{ lb.}$$

The weight of dry air present is found from the well-known formula for air

$$P_1 V_1 = RT_1$$

Where P_1 = pressure in lb. per sq. ft. of dry air
V_1 = volume in cu. ft. of 1 lb. of dry air
T_1 = absolute temperature
= 459.6 + observed temperature above zero F.
R = 53.35

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Then weight of dry air

$$W_a = \frac{1}{V_1} = \frac{P_1}{R\,T_1}$$
$$= \frac{144 \times 14.1032}{53.35\ (459.6+78)}$$
$$= 0.070756$$

The weight per cu. ft. of the air and its accompanying vapor then becomes

$$W_v + W_a = 0.000591 + 0.070756$$
$$= 0.071347$$

And the volume in cu. ft. per lb.

$$V_m = \frac{1}{0.071347}$$
$$= 14.015 \text{ cu. ft.}$$

When it is desired to measure air with a Thomas electric meter, the mean specific heat of the mixture of air and water vapor must be known. The United States Bureau of Standards gives for the specific heat of air at constant pressure the following value:

$$C_{pa} = 0.240395 + 0.0000089\ t.*$$

where t = temperature in degrees F.

For mean specific heat of water vapor at constant pressure, Carpenter and Diederichs* gives:

$C_{ps} = 0.4519 + 2.27 \times 10^{-6}\ t + 2.89 \times 10^{-8}\ t^2 - 3.53 \times 10^{-12}\ t^3$.

where t = mean temperature in degrees F.

Applying these values to the preceding conditions, namely, 78° F

$$C_{pa} = 0.24109$$

and

$$C_{ps} = 0.45225$$

The average specific heat can then be found by multiplying the weight of each substance in the mixture by its specific heat, adding the products, and dividing the sum by the total weight of the mixture.

Thus

For air $0.070756 \times 0.24109 =$	0.017059
For water vapor $0.000591 \times 0.45225 =$	0.000267
	0.017326

$$\text{Average specific heat} = \frac{0.017326}{0.071347}$$
$$= 0.2427$$

*These values in centegrade units can be found on page 865, *Experimental Engineering*, by Carpenter & Diederichs.

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This value is then used in the formula for the Thomas meter.

The above principles are applied commercially in testing steam condensers. An accurate thermometer is placed in the suction to the dry air pump and a mercury column attached to the same. In a condenser the conditions are such that the mixture is always saturated. Hence the pressure due to water vapor passing to the air pump will equal that due to its temperature as given by the steam tables. Then the difference between this and the pressure shown by the mercury column will equal the pressure due to the dry air in the mixture. If the volumetric efficiency of the air pump is known, the amount of air pumped can be computed, and this gives a means of readily checking the condensing equipment for air leakage.

Experiment No. 44

TEST OF A REFRIGERATING MACHINE

In the usual type of heat engine operating on a direct cycle, heat is added to the machine at high temperature, a certain amount is expended in useful work and the greater part of the heat escapes through the exhaust at a low temperature to the cold body or refrigerator.

The refrigerating machine reverses this process. It takes heat from the cold body or refrigerator, through the exhaust pipe so to speak. Work is done on the working substance in compressing it and the heat equivalent of this work raises its temperature.

In the direct acting engine, maximum efficiency is obtained when working on the Carnot cycle. In the refrigerating machine the maximum efficiency is obtained when the Carnot cycle is reversed.

The efficiency of an engine on the direct cycle is the ratio of the useful work done, in equivalent B.t.u., to the heat supplied. If W_1 = useful work done, $A = \frac{1}{778}$ and H_1 = heat supplied in the steam to the engine above the heat of the liquid at exhaust pressure, then thermal efficiency

$$E = \frac{AW_1}{H_1}$$

With the refrigerating machine working on a reversed cycle, the useful work done is the removal of H_2 heat units from the brine and the heat expended in doing so is the mechanical work W_2 equal to the i.h.p. of the ammonia cylinder.

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Hence the efficiency of a refrigerating machine may be represented as follows:

Efficiency

$$E = \frac{H_2}{AW_2}$$

Now the heat absorbed from the refrigerator may be many times that expended in useful work in compressing the working substance. Hence the efficiency of a refrigerating machine as expressed above may exceed unity by considerable amounts.

Working Fluids

The principles of the different machines vary somewhat for the different working fluids. The principal fluids in use are air, ammonia, and carbon dioxide. The properties desirable in a vapor or gas for refrigeration purposes are:

1. Large heat of vaporization which will permit the use of a small amount of working substance. The capacity of a given weight of the substance to transfer heat is proportional to this quantity.

2. Freezing point low. The lower the temperature at which the working fluid will remain liquid the greater the capacity to absorb heat for a given weight since this capacity is a function of the difference of temperature. A lower temperature in the refrigerator can also be obtained in this way.

3. The working fluid must have considerable change in temperature for moderate increases in pressure, it must be cheap and must not attack the metal of the machines.

For the description of refrigerating machines using air, carbon dioxide, or water-vapor, the student is referred to some standard text on the subject.

Ammonia is said to be "anhydrous" when it has been purified and freed from water. It is the working fluid most commonly used in ice machines of either the compression or absorption class.

A table of the properties of ammonia will be found at the end of this book or in Goodenough's *Tables*. The machine in the laboratory is of the compression type and works on the following principle:

Ammonia gas is drawn from the ammonia coils of the refrigerator into the compressor cylinder and is then compressed to the higher pressure by work supplied from the direct connected steam engine. It next passes to a condenser where it is cooled and liquified. During this change not only the heat due to compression but also the

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heat of vaporization at this pressure is carried away by the cooling water. The liquid ammonia, still at the high pressure, is conducted to the refrigerator coils and is allowed to expand through a small needle valve, usually known as the expansion valve, to the pressure of the suction.

On account of the low boiling point of ammonia at this pressure, the liquid commences to evaporate. In order to evaporate, the liquid ammonia must absorb heat equal to its latent heat of evaporation at the pressure of the refrigerator. The only source of heat available is the refrigerator and thus the ammonia absorbs heat from it, lowering its temperature.

The capacity of the compressor cylinder depends on the temperature of the suction gas. Therefore, in order to obtain maximum efficiency it is desirable to keep the entering gas at as near the temperature of the refrigerator as possible. For this purpose all the return piping is heavily lagged between the refrigerator tanks and the compressor cylinder. Even with this protection the gas absorbs some heat from the air.

The ends of the ammonia piston are spherical and the inlet and discharge valves are so placed that the clearance is reduced to a minimum. On the machine in the laboratory this axial clearance is about 1/32 in. at each end.

Brine consisting of a solution of chloride of calcium is used as the freezing mixture in the laboratory.

A table of the properties of calcium chloride brines is included in the appendix.

In an ice making plant, the brine at a low temperature surrounds the tanks containing the clear water to be frozen. It absorbs heat from this water until it solidifies into a solid mass of ice. This heat is taken from the brine in turn by the ammonia gas.

In cold storage warehouses, the brine, after passing around the ammonia coils, is circulated by a pump through cooling coils in the various rooms. The temperature of the brine is regulated by adjusting the ammonia supply to produce the desired degree of cold in the warehouse.

In the laboratory tank, heat is provided to the brine by heating it with steam before returning it to the refrigerator. The brine is circulated by means of a small motor-driven centrifugal pump.

The refrigerator plant is shown diagrammatically in Fig. 31.

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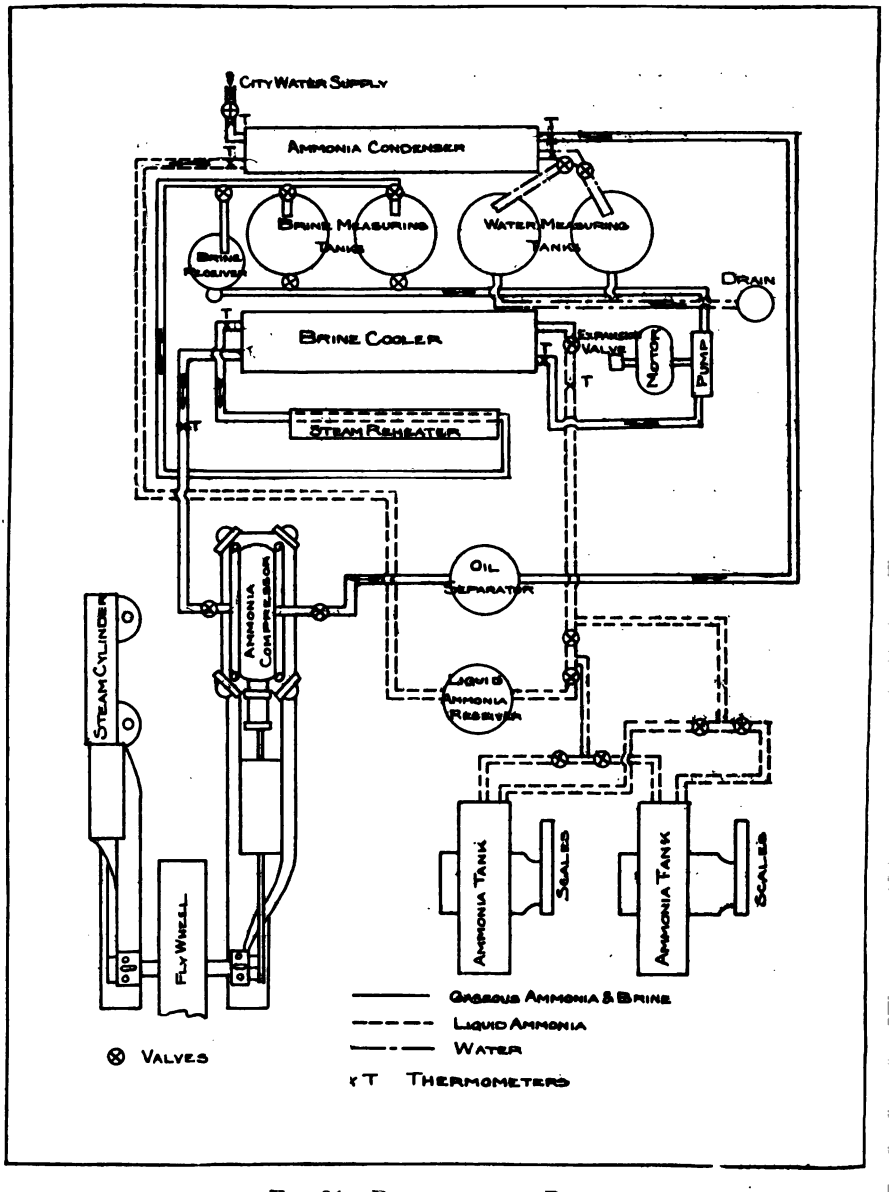

FIG. 31. REFRIGERATION PLANT

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METHOD OF TEST

The object of the test should be clearly defined and kept in mind during the whole of the test. This may be a determination of the ice-making capacity of the machine, or of the amount of ice for a given amount of steam or coal, or to determine the efficiency of the machine itself.

For complete instructions regarding the performance of tests on refrigerating machines, the student is referred to the "Report of the Committee on Refrigerating Machines" *Transactions A. S. M. E.* Vol. 28. The recommendations made in this report will be followed in the laboratory work.

All thermometers should be carefully calibrated before a test. The freezing point 32° F. should be checked by inserting in a bath of melting ice. Other points may be checked by comparison with a standard thermometer. Glass thermometers with the graduations marked on the stem should be used. Thermometer cups should project at least two inches into the space where the fluid circulates. The thermometers should be placed in these cups so that the top of the column projects above the well and a reading can be made without moving it.

It is usually necessary to measure the range of temperature through which the refrigerating fluid is cooled in order to determine the capacity of the machine. These readings must be taken with the highest degree of accuracy and very small increments of temperature must be noted.

It is well to interchange the thermometers which are used for measuring the temperatures of inlet and outlet brine several times during a test making a note of such changes on the record of the test.

Tanks are provided for measuring the amount of cooling water to the condenser and the amount of brine circulated. They are 2½ ft. in diameter and 8½ ft. high and are calibrated on a graduated scale for 70° F. temperature of fluid and for a specific gravity of the brine of 1.264. Corrections must be made to the brine readings if its specific gravity varies from this amount.

The ammonia condenser consists of two vertical tiers of eight pipes, each 17 feet long. The inside diameter of the ammonia pipes is 2 in. and of the water cooling pipes 1¼ in. The condensing surface is 89.5 sq. ft.

The brine cooler has one vertical tier of 15 pipes 15 ft. long. The inside diameter of the ammonia pipes is 3 in. and the inside diameter

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of the brine pipes is 2 in. The cooler has 158 sq. ft. of cooling surface.

The brine in the experimental outfit is reheated in a steam reheater which consists of a 4 in. jacket pipe, 18 ft. long surrounding the brine pipe as it leaves the brine coils on its way to the storage tank in the balcony.

The arrangement of tanks for weighing the amount of ammonia circulated is such that this can be done with great accuracy. Two tanks are provided and by manipulating the valves the ammonia can all be weighed. Care must be taken that the tanks empty themselves in each case, that the level of the ammonia in the receiver is held constant, and that one set of valves is shut tightly before another set is opened.

As the actual refrigerating effect is measured by the cooling produced in the brine circulated, the specific gravity and the specific heat of the brine should be determined.

The pressure of the ammonia gas leaving the refrigerator may be taken as equal to that in the refrigerator itself. Unless the gas leaving the refrigerator is superheated, i. e., has a temperature in excess of that corresponding to the pressure there will be some liquid ammonia leaving the refrigerator and hence an error will be introduced as the calculated results will be too great by this amount of liquid. Hence a thermometer must be placed in the suction pipe from the refrigerator. If possible another thermometer should be placed at the suction to the compressor itself.

A thermometer should also be placed in the liquid pipe before the liquid ammonia reaches the expansion valve.

On account of the low temperature of ammonia at suction, a special grade of cylinder oil with low chill point must be used for lubricating the ammonia cylinder. The oil is forced in by a small hand pump.

Ammonia will destroy any brass or copper parts with which it comes in contact. Special indicators made of steel throughout must, therefore, be used on ammonia cylinders.

The steam cylinder of this set is 9 in. x 24 in. while the ammonia cylinder is 8 in. x 16 in. The piston rods on both steam and ammonia are $1\frac{11}{16}$ in. diameter. The engine should run at about 100 r.p.m.

The commercial tonnage capacity per 24 hours should be computed from the formula:

$$R_1 = \frac{W_1 \times 24}{144 \times 2000} \left\{ \lambda_2 - q_1 + C_p (t_3 - t_2) \right\},$$

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where 144 = latent heat of fusion of ice per lb.

R_1 = commercial tonnage capacity or tons of ice melting capacity per 24 hours.

*W_1 = weight of anhydrous ammonia evaporated in the refrigerating coils in lb. per hour.

λ_2 = total heat above 32° F. of one lb. of the saturated ammonia gas at the pressure of the refrigerator.

q_1 = the heat of the liquid ammonia above 32° F. at the temperature observed before it passes through the expansion valve.

C_p = the specific heat of superheated ammonia gas at constant pressure = 0.51.

t_3 = the average temperature of the superheated ammonia gas leaving the refrigerator in degrees F.

t_2 = the average temperature corresponding to the pressure at which the ammonia gas leaves the refrigerator in degrees F. or $\lambda_2 + C_p(t_3 - t_2)$ may be taken from ammonia tables.

The above tonnage capacities are calculated on the basis of the refrigerating effect of the anhydrous ammonia. The actual refrigerating capacity, however, should be calculated on the basis of the cooling of the brine and can be found by the following formula:

$$R_2 = \frac{W_2 \times 24}{144 \times 2000} \times C(t_5 - t_4),$$

where R_2 = actual tonnage capacity or tons of ice melting capacity per 24 hours.

W_2 = weight of refrigerating fluid circulated per hour.

C = specific heat of refrigerating fluid for the range of temperatures existing in the tests.

t_5 = temperature of refrigerating fluid returned to the coils in degrees F.

t_4 = temperature of refrigerating fluid leaving the coils in degrees F.

When the final temperature of the brine differs from that at the beginning of the test, a positive or negative correction must be made for this heat. This correction is found by multiplying together the net weight of brine in the system, the difference between initial and final temperature and the specific heat of the brine.

*W_1 should be corrected for the weight of ammonia gas that remains in the weighing tanks, since if this is not done it will introduce a very appreciable error in the results.

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The preceding formula then becomes

$$R_3 = \frac{24}{144 \times 2000}\left\{W_2\, C\,(t_5 - t_4) + \frac{W_2}{D}\, C\,(t_7 - t_6)\right\}$$

where R_3 = corrected tonnage capacity or tons of ice melting capacity per 24 hours.

W_2 = net weight of brine in system.

D = duration of test in hours.

t_7 = temperature of refrigerating fluid entering the freezing coils in degrees F. at start of test.

t_6 = temperature of refrigerating fluid entering the freezing coils in degrees F. at the end of test.

In some cases $(t_7 - t_6)$ may be a negative quantity and the correction will therefore be negative.

Directions for Test

Place indicators on the steam cylinder with reducing motions and provide means of weighing the condensed steam from the surface condenser.

Place a calorimeter on the steam supply and determine the quality of the entering steam.

Attach a speed counter to read the number of revolutions.

Place the special ammonia indicators on the ammonia cylinder and provide reducing motions.

Start the compressor and brine circulating pump and operate for an hour to get all conditions constant; while conditions are becoming settled, place thermometers to read the temperature of the ammonia gas entering and leaving its condenser and leaving the brine tank, of the liquid ammonia just before it reaches the brine coils, of the cooling water entering and leaving the ammonia condenser, of the brine entering and leaving the refrigerator, of the room, and if possible of the ammonia gas entering and leaving the compressor.

Find the specific gravity of the brine by means of a hydrometer.

Make a test with constant suction and discharge pressures.

Keep records on forms as follows.

Report test according to the following A. S. M. E. form.

In the following forms the term "refrigerator" refers to the brine cooler. The pressure in the refrigerator is assumed the same as the suction pressure of the ammonia compressor.

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Form No. 1. TEST OF.....REFRIGERATING MACHINE

Steam engine results

Test made at..... Date.....
Barometer..... Observers.....
Diameter of cylinder..... Area of piston rod.....
Diameter of piston rod..... Area of piston, head.....
Length of stroke..... crank.....

Time	Pressures		Speed counter	Condensed steam lb.	Horsepower					Temperatures		
					H. E.		C. E.		Total i.h.p.			
	Steam	Back pressure in calorimeter			m.e.p.	i.h.p.	m.e.p.	i.h.p.		Calorimeter	External air	Room

Form No. 2. TEST OF.....REFRIGERATING MACHINE

Ammonia compressor data

Test made at..... Date.....
Barometer..... Observers.....
Diameter of cylinder..... Area of piston rod.....
Diameter of piston rod..... Area of piston, head.....
Length of stroke..... crank.....
Volume per stroke, head.....crank.....

Time	Ammonia Pressure		Temperature					Horsepower					Net weight of ammonia circulated
			Ammonia		Jacket water			Head		Crank			
	Suction	Discharge	Suction	Discharge	Entering	Leaving	Pounds	m.e.p.	i.h.p.	m.e.p.	i.h.p.	Total i.h.p.	

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Form No. 3. TEST OF.....REFRIGERATING MACHINE

Ammonia condenser and brine cooler data

Ammonia condenser	*Brine cooler*
No. of pipes.....	No. of pipes.....
Diameter of ammonia pipe.....	Diameter of ammonia pipe.....
Diameter of water pipe.....	Diameter of brine pipe.....
Length of pipes.....	Length of pipes.....
Cooling surface, sq. ft.....	Cooling surface, sq. ft.....
Specific gravity of brine.....	Date of test.....
Specific heat of brine.....	Observers.....

Time	AMMONIA CONDENSER					BRINE COOLER				
	Temperatures °F.				Weight of cooling water, lb.	Temperatures °F.				Weight of brine cooled, lb.
	Ammonia		Cooling water			Ammonia		Brine		
	In	Out	In	Out		In	Out	In	Out	

Form No. 4. GENERAL RESULTS OF TEST OF.....REFRIGERATING MACHINE

Based on A. S. M. E. forms

1. Test made by.....
   On machine located at.....
   To determine.....
2. Type of engine driving compressor.....
3. Type of ammonia cylinder, single or double acting.....
4. Name of builders.....
5. Data regarding steam cylinders.
   Bore, in.....
   Stroke, in.....
   Diameter of piston rod, in .....
   H. P. constant for 1 lb. m.e.p. and 1 r.p.m.....
   Percentage of clearance, head.....
   crank.....
6. Data regarding ammonia cylinders.
   Number of cylinders.....
   Vertical or horizontal.....
   Bore, in.....
   Stroke, in.....
   Diam. of piston rod, in.....
   Percentage of clearance, head.....
   crank.....
7. Water wetted surface of condenser coils, sq. ft.....
8. Water wetted surface of refrigerator coils, sq. ft.....
9. Date of trial.....
10. Duration of test.....

HOURLY QUANTITIES

11. Anhydrous ammonia evaporated in refrigerating coils, lb.....
12. Brine circulated, lb.....
13. Condensing water, lb.....
14. Water circulated through compressor jackets, lb.....
15. Steam supplied to engine driving compressor, lb.....
16. Quality, per cent.....
17. Dry steam supplied to engine driving compressor, lb.....

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Pressures and Temperatures (Corrected)

(Average for test except Nos. 25 and 26).

18. Condenser pressure, gage, lb. per sq. in.....
19. Refrigerator pressure, gage, lb. per sq. in.....
20. Temperature of liquid ammonia just before expansion valve, deg. F.....
21. Temperature of ammonia gas leaving refrigerator, deg. F.....
22. Temperatre of brine entering brine cooler, deg. F.....
23. Temperature of brine leaving brine cooler, deg. F.....
24. Range of temperature of brine, deg. F.....
25. Temperature of brine at beginning of test, deg. F.....
26. Temperature of brine at end of test, deg. F.....
27. Temperature of condensing water supplied to condenser, deg. F.....
28. Temperature of condensing water leaving condenser, deg. F.....
29. Temperature of air at condenser, deg. F.....
30. Temperature of cooling water supplied to jackets, deg. F.....
31. Temperature of cooling water leaving jackets, deg. F.....
32. Temperature of gas entering the compressor, deg. F.....
33. Temperature of gas leaving the compressor, deg. F.....
34. Temperature of the engine room, deg. F.....
35. Barometer.....in. mercury.....

Data Relating to Amount of Refrigeration Produced

36. Cooling effect per pound of anhydrous ammonia circulated, B.t.u. $=\lambda_2 - q_1 + C_p (T_3 - T_2)$.....
37. Density of brine.....
38. Specific heat of brine.....
39. Total weight of brine in system (used when there is a correction for difference in temperature of brine at the beginning and end of test).....

Tonnage

40. Tonnage capacity computed from the amount of ammonia circulated.....
41. Actual tonnage capacity computed from the weight of brine circulated and corrected for any difference in temperature of the brine at the beginning and end of the test.....

Condensing and Circulating Water

42. Total cooling water for all purposes in gal. per min. per ton of refrigeration produced per 24 hours, gal.....

Steam Engine and Compressor Data

43. Average r.p.m.....
44. Pressure of steam at throttle, gage, lb. per sq. in.....
45. Indicated horsepower steam cylinder.....
46. Indicated horsepower ammonia cylinder.....
47. Friction in per cent of steam horsepower.....
48. Steam supplied to engine per hour per horsepower, lb.....
49. Refrigeration in pounds of ice melting capacity per hour per horsepower of engine, lb.....

Economy

50. Ice melting capacity in lb. per lb. of coal fired assuming each pound of coal imparts 10,000 B.t.u. to the steam, lb.....
51. Efficiency of the refrigerating plant.....

Heat Balance

All quantities computed in B.t.u. per hour

52. Refrigerating effect based on the weight of ammonia evaporated in refrigerator, B.t.u.
53. Heat, equivalent to work of compressing ammonia, (horsepower of ammonia cylinders x 2546.5 B.t.u).....
54. Total heat discharged=sum of (52) and (53), B.t.u.....
55. Heat imparted to condenser water, B.t.u.....
56. Heat imparted to jacket water, B.t.u.....
57. Heat dispersed=sum of (55) and (56), B.t.u.....
58. Radiation and unaccounted for losses=difference of (54) and (57), B.t.u.....

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EXPERIMENT NO. 45

TEST OF A STEAM NOZZLE

The object of this experiment is to familiarize the student with the changes and losses that take place during the passage of steam through a nozzle, and the methods of determining the same.

The nozzles and accompanying test apparatus shown in Fig. 32, were designed after that used by Stodola on his classic experiments on nozzles. It consists of a section A of 2 in. pipe to act as a protector to the search tube. The section B is made of brass with a registered joint where it connects to nozzle C. B carries a thermometer well and also a yoke which supports one end of the search tube. C is the nozzle which is provided with five ¼ in. pipe taps along one side to which pressure gages can be attached. These connect by 1/32 in. holes to the wall of the nozzle. The connected gages will then indicate the pressure at the wall of the nozzle if so desired. There is also a thermometer well on one side of the nozzle which can be used with superheat. D is a special brass casting which connects to both C and E with registered joints, and contains two thermometer wells. The steam supply connects to the side branch of D and is ample for the amount of steam required by the nozzle. E consists of the supporting and operating mechanism connected with the search tube. The search tube is 3/16 in. brass tube 18 in. long, and has a 1/16 in. hole at right angles to its axis, 7¾ in. from the end. Its outer end is supported by the yoke previously referred to. This tube is connected to a larger brass tube held in a long stuffing box in E, as shown, and connected at its outer end to a casting provided with a ¼ in. pipe tap for a gage. Guides with indicating devices support this tube along the yoke supports. A screw with a hand wheel is provided so that the position of the openings in the search tube can be shifted in the nozzle as desired. The position of these holes can be determined from the graduated scale on one of the supporting arms of the yoke.

All parts are accurately fitted and all steam portions painted black to reduce radiation. The joints are made up with thin sheets of oiled paper. Four nozzles are provided which can be used in the apparatus. Each nozzle is 7 in. long and all are alike as regards outside appearances and dimensions. They differ, however, in the angles of flare of the inside as shown in the following table. The

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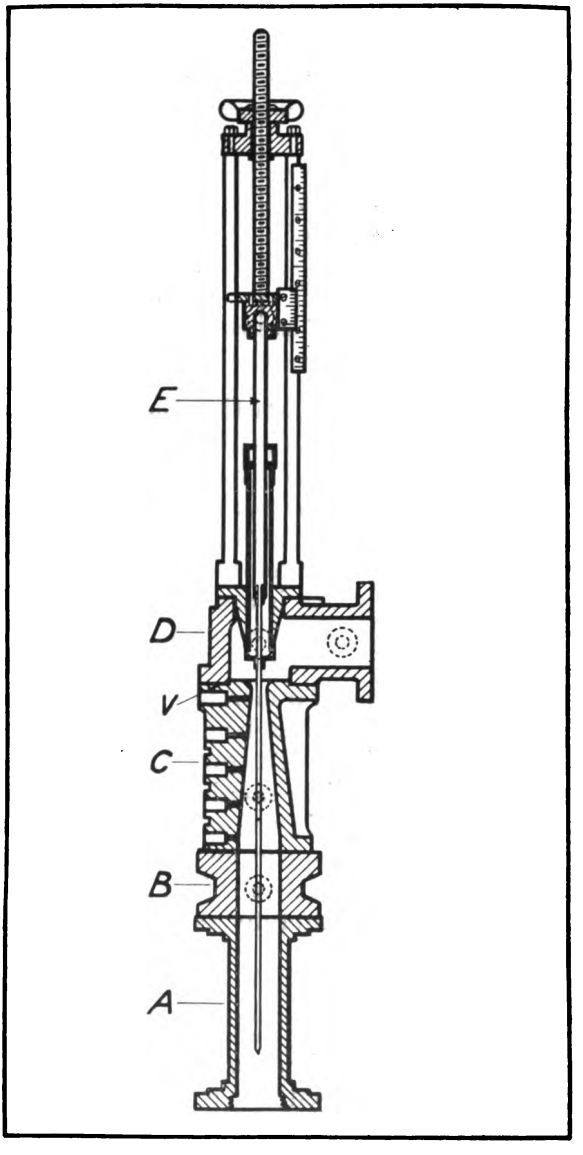

FIG. 32. APPARATUS FOR TESTING STEAM NOZZLES

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inside surfaces are accurately machined and highly polished to reduce friction losses to a minimum.

DIMENSIONS OF NOZZLES

Nozzle No.	1	2	3	4
Face V to hole 1.....in.	.377	.384	.350	.369
Diameter of throat at hole 1.....in.	0.5	0.5	0.5	0.5
Hole 1 to hole 2.....in.	1.507	1.507	1.517	1.492
Hole 1 to hole 3.....in.	2.985	3.001	3.003	2.990
Hole 1 to hole 4.....in.	4.479	4.496	4.501	4.486
Hole 1 to hole 5.....in.	5.998	6.008	6.014	6.008
Hole 1 to mouth of nozzle.....in.	6.370	6.391	6.491	6.475
Diameter of mouth.....in.	1.248	1.507	1.868	2.21
Angle.....	6°—43′—39″	9°—1′—0″	12°—2′—10″	15°—4′—0″

It was found by close measurement that the indicator on the yoke read 0.22 in. when the holes were opposite the face V. Therefore, the indicator would show 0.597 in., 0.604 in., 0.57 in. and 0.59 in. in the four nozzles when the holes in the search tube are opposite hole 1. The holes are numbered from the end of the nozzle at which the steam enters. The approach to the throat is well rounded on all nozzles.

The apparatus described above is assembled in the laboratory so that the pressure and quality of the steam from the main can be determined. The pressure in the search tube can be read either from an accurate gage or by means of a mercury column. The pressures along the sides of the nozzle can also be measured by pressure gages or mercury columns if so desired. The pressure in the exhaust can be regulated by a valve between the nozzle and the condenser. The steam discharged is condensed in the condenser connected to the air compressor so that a vacuum can be maintained in the exhaust when so desired. This vacuum should be measured by a mercury column. All gages should be carefully calibrated before the test is made.

TO PLOT A VELOCITY CURVE WITH NO LOSSES

The ideal expansion of steam in a nozzle is adiabatic and without losses. To plot a velocity curve with such an expansion, the following computations are necessary.

The pressure and quality of the steam supplied are determined from the experiment and the total heat entering H_1 can be determined from a heat diagram. Assume any absolute pressure P_m and on the Mollier chart find the heat H_m in the steam after it has expanded adiabatically to P_m.

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Then

$$A\frac{v_m^2}{2g} = H_1 - H_m$$

where $A = \frac{1}{778}$ and v_m = velocity in ft. per sec. after adiabatic expansion to absolute pressure P_m.

Omitting the very small initial velocity of the steam as it arrives at the nozzle

$$v_m = \sqrt{\frac{2g}{A} \cdot (H_1 - H_m)}$$

$$= 223.7\sqrt{H_1 - H_m}$$

The volume discharged per second at any pressure equals the weight discharged per second multiplied by the specific volume of the steam at that pressure and quality. But the law of steady flow requires that volume discharge per second = area of section × velocity per second.

Hence

$$G\, x_m\, S_m = \frac{a_m\, v_m}{144}$$

where G = pounds of steam discharged per second.

x_m = quality at pressure P_m after adiabatic expansion, found from Mollier chart.

S_m = specific volume of one pound of steam.

a_m = required area of nozzle in sq. ins. where pressure would be P_m if the expansion were adiabatic.

Then

$$a_m = \frac{144\, G\, x_m\, S_m}{v_m}$$

By calculating a number of such cross sections, a curve can be plotted showing the velocity at different points along the nozzle.

To Find the Actual Velocities in the Nozzle

If y = per cent friction loss in nozzle then the theoretical equation changes to

$$A\frac{v_2^2}{2g} = (H_1 - H_m)\,(1 - y)$$

and

$$V_2 = 223.7\,\sqrt{(H_1 - H_m)\,(1 - y)}$$

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As before the pressure, quality, and total heat of the steam arriving at the nozzle, and the weight of steam flowing per second, are known from the test. From the readings of the search tube, at any section a_2 the pressure is P_2 from test.

Let v_1 = initial velocity of the steam before arriving at the nozzle, and $A = \frac{1}{778}$ as before.

At cross section a_2 the steam is wet but with an unknown quality x_2 since expansion is not adiabatic.

At a_2 the heat in the steam is

$$H_2 = x_2 r_2 + q_2$$

where r_2 = latent heat of vaporization

and q_2 = heat of the liquid.

Let v_2 = unknown velocity at a_2,

Then the velocity equation becomes

$$A\frac{v_2^2}{2g} = A\frac{v_1^2}{2g} + H_1 - (x_2 r_2 + q_2)$$

Also

$$G x_2 S_2 = \frac{a_2 v_2}{144}$$

$$\therefore x_2 = \frac{a_2 v_2}{144 G S_2}$$

Substituting in velocity equation

$$A\frac{v_2^2}{2g} = A\frac{v_1^2}{2g} + (H_1 - q_2) - \frac{a_2 r_2}{144 G_2 S_2} \cdot v_2$$

The factor $A\frac{v_1^2}{2g}$ is very small and may be neglected without appreciable error.

Then

$$v_2^2 + \frac{2g\, a_2 r_2}{144 A G S_2} \cdot v_2 - \frac{2g}{A}(H_1 - q_2) = 0$$

$$\therefore v_2 = 173.97 \left\{ -\frac{a_2 r_2}{G S_2} + \sqrt{\left(\frac{a_2 r_2}{G S_2}\right)^2 + 1.6554 (H_1 - q_2)} \right\}$$

$$x_2 = \frac{a_2 v_2}{144 G S_2}$$

From the preceding $V_m = 223.7 \sqrt{H_1 - H_m}$ and at same point $V_2 = 223.7 \sqrt{(H_1 - H_m)(1 - y)}$

$$\therefore \sqrt{1-y} = \frac{V_2}{V_m}$$

$$\text{or } y = \%\ \text{loss} = 1 - \left(\frac{V_2}{V_m}\right)^2$$

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From a series of such computations the actual velocity curve and a curve showing the percentage of loss at various points of the nozzle can be plotted.

Directions for Test

Carefully calibrate the steam gages.

Attach a calorimeter and provide for weighing the condensed steam.

Make three tests with varying back pressure on the nozzle provided, reading very accurately the position of the search tube and its pressure. Take readings of the pressure of the steam supplied, the throttling calorimeter readings, the position of the search tube and the indicated pressure, the pressures along the side of the nozzle, the back pressure, and the amount of condensed steam.

Temperatures along the nozzle need not be taken unless superheat is used.

Log forms are to be prepared by the students performing the experiment.

The report of the test should show the methods of computation and tabulated results.

At the top of a sheet of cross-section paper draw to scale a section of the nozzle. Draw a curve at the bottom of the sheet showing the area corresponding to any section of the nozzle above, making proper allowance for the area of the search tube. This will aid in computing velocities.

Plot curves on this same sheet showing pressures at various points in the nozzle as observed by exploring with a search tube in the tests.

Select the test showing the best expansion curve and from these results plot curves showing the actual velocities in the nozzle, the velocities from adiabatic expansion, and the actual losses in the nozzle.

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EXPERIMENT NO. 46

PLANT TEST

The experimental work in the steam and gas engineering laboratories familiarizes the students with individual machines, the method of testing these machines, the instruments used, and the possible sources of error in such work. It is desirable that an opportunity be given to apply this knowledge to the test of a group of machines in a commercial plant and arrangements will be made each year to carry out such a test. The types of machinery installed, the relation of these machines to one another, and the factors entering into commercial operation can thus be studied.

Such a test will extend for a period of twelve hours or longer and the class will be divided into sections as found desirable. The time and place of such test will be announced during the semester and the men will be assigned to work by the instructor in charge. Full instructions regarding the test will be given by the instructor.

In such a test the greatest accuracy must be observed in making each observation, or in weighing any material, and a sharp look-out should be kept to see that everything is working properly and that no errors are being made. While each man will have certain definite duties to perform, he is expected to inform himself as to the details of the test by walking around the plant when possible and asking questions of the other men and the instructor in charge.

The final report must contain a full description of the plant and the methods used in testing it. It should be written up in the form of a commercial report to the owner of the plant. Data for the entire test will be furnished to each man a few days after the test is completed.

Men should report on the test one-half hour before their section goes on duty in order to acquaint themselves with the readings they are to take.

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APPENDIX

According to Naumann, a solution of 1.0255 sp. gr. has a specific heat of 0.957. A solution of 1.163 sp. gr. in the test reported in *Engineering*, July 22, 1887, gave a specific heat of 0.827.

H. C. Dickson (*Science*, April 23, 1909) gives the following values of the specific heat of solutions of chemically pure calcium chloride:

TABLE 1

DENSITY	SPECIFIC HEAT	TEMPERATURE C
1.07	0.869 + 0.00057 t	(— 5° to + 15°)
1.14	0.773 + 0.00064 t	(—10° to + 20°)
1.20	0.710 + 0.00064 t	(—20° to + 20°)
1.26	0.662 + 0.00064 t	(—25° to + 20°)

The advantages of chloride of calcium solution are its lower freezing point and that it has little or no corrosive action on iron and brass. Calcium chloride is sold in the fused or granulated state, in steel drums, containing about 75 per cent anhydrous chloride and 25 per cent water, or in solution containing 40 to 50 per cent anhydrous chloride in tank cars. The following data are taken from the catalogue of the Carbonale Calcium Co.:

TABLE 2

PROPERTIES OF "SOLVAY" CALCIUM CHLORIDE SOLUTION

Deg. Baume, 60° F	Spec. Grav., 60° F	Per cent Ca.Cl.	Freezes at Deg. F.
1.	1.007	1	+31.10
5.5	1.041	5	27.68
11	1.085	10	22.38
17	1.131	15	12.20
20	1.159	18	4.64
21	1.169	19	+ 1.76
22	1.179	20	— 1.48
23	1.189	21	— 4.90
26	1.219	24	—17.14
29	1.250	27	—32.62
32	1.283	30	—54.40
35	1.316	33	—25.24
35.5	1.327	34	— 9.76
36.5	1.338	35	+ 2.84
37.5	1.349	36	+14.36

Quantity of 75 per cent calcium required to make solutions of different specific gravities and freezing points.

Sp. gravity	1.250	1.225	1.200	1.175	1.150	1.125	1.100
Lbs. per cu. ft. solution	28.06	25.06	22.05	19.15	16.26	13.47	10.70
Lbs. per gallon	3.76	3.36	2.95	2.56	2.18	1.80	1.43
Freezing point °F	—32.6	—19.5	— 8.7	Zero	+ 7.5	+13.3	+18.5

Boiling points of calcium chloride solutions:

Sp. gr. at 59° F	1.104	1.185	1.238	1.341	1.383 solid at 59°			
Boiling point °F	215.6	221.0	230.0	240.8	248.0	266.0	282.2	306.5
Sp. gr. at boiling point	1.085	1.119	1.209	1.308	1.365	1.452	1.526	1.619

NOTE:—Copied from Kent's *Mechanical Engineer's Pocket Book*, 9th Edition, 1916, Page 1343.

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TABLE 3

Specific Heat of Gases

Gas	One pound	One cubic foot
Carbon dioxide CO_2	0.19 +0.00006 t B.t.u.	0.023 +0.000008 t B.t.u.
Carbon monoxide CO	0.24 +0.0000119 t B.t.u.	0.0189 +0.0000009 t B.t.u.
Water vapor H_2O	0.42 +0.000103 t B.t.u.	0.021 +0.000005 t B.t.u.
Oxygen O_2	0.2104 +0.0000104 t B.t.u.	0.0189 +0.0000017 t B.t.u.
Nitrogen N_2	0.2405 +0.0000214 t B.t.u.	0.0189 +0.0000017 t B.t.u.

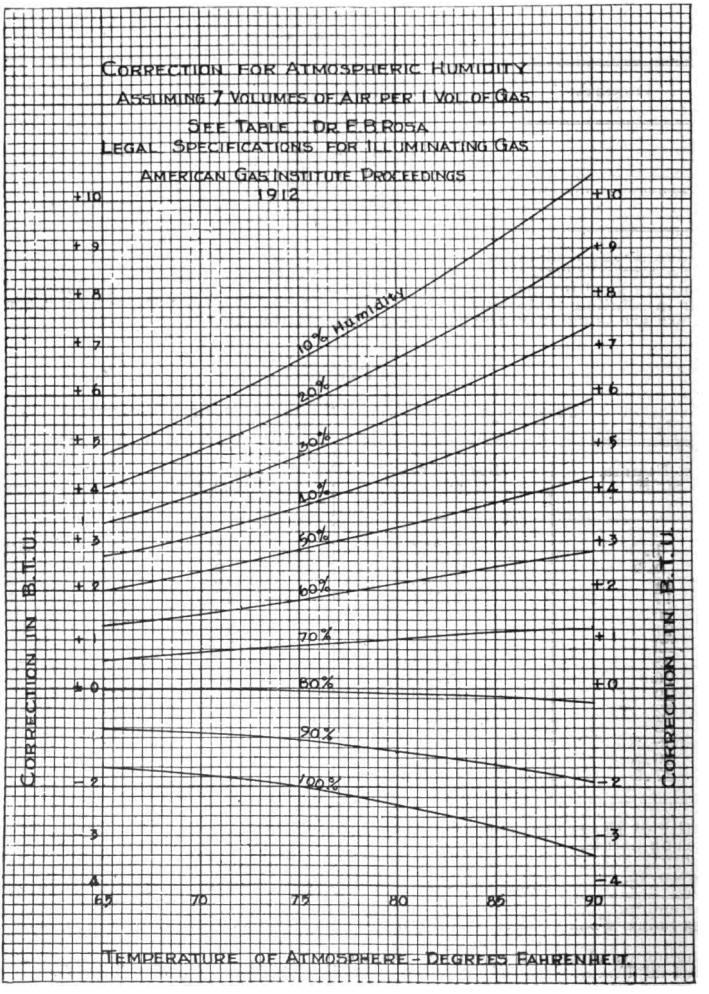

FIG. 33. HUMIDITY CORRECTION CURVES FOR JUNKER'S CALORIMETER

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TABLE 4

Tension of Water Vapor in Inches of Mercury

Temperature F°	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
30	.167	.174	.181	.188	.196	.204	.212	.220	.229	.238
40	.247	.257	.267	.277	.288	.299	.311	.323	.335	.348
50	.361	.374	.388	.403	.418	.433	.449	.465	.482	.500
60	.518	.537	.556	.576	.596	.617	.639	.661	.685	.708
70	.733	.759	.785	.812	.840	.868	.897	.927	.958	.990
80	1.023	1.057	1.092	1.128	1.165	1.203	1.242	1.282	1.333	1.366
90	1.401	1.455	1.501	1.548	1.596	1.646	1.697	1.751	1.806	1.862

DATA AND RESULTS OF STEAM-ENGINE TEST

Code of 1915

(1) Test of.....engine located at.....
To determine.....
Test conducted by.....

DIMENSIONS, ETC.

(2) Type of engine (simple or multiple expansion).....
(3) Class of service (mill, marine, electric, etc.).....
(4) Auxiliaries (steam or electric driven).....
(*a*) Type and make of condenser equipment.....
(*b*) Rated capacity of condenser equipment.....h. p.
(*c*) Type of oil pump, jacket pump, and reheater pump (direct or independently driven).....

(5) Rated power of engine.....
(*a*) Name of builders.....
(*b*) Kind of valves.....
(*c*) Type of governor.....

	1st	2d	rd
(6) Diameter of cylinders.....in.	.....	.....	.....
(7) Stroke of pistons.....ft.	.....	.....	.....
(*a*) Diameter of piston rod, each end.....in.	.....	.....	.....
(8) Clearance (average) in per cent of piston displacement.....	.....	.....	.....
(9) H.P. constant 1 lb. 1 rev.....h.p.	.....	.....	.....
(*a*) Cylinder ratio (based on net piston displacement).....1 to —	.....	.....	.....
(*b*) Area of interior steam surface.....sq. ft.	.....	.....	.....
(*c*) Area of jacketed surfaces.....sq. ft.	.....	.....	.....
(10) Capacity of generator or other apparatus consuming power of engine.....h.p.	.....	.....	.....

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Date and Duration

(11) Date.....

(12) Duration.....hr.

Average Pressures and Temperatures

(13) Pressure in steam pipe near throttle, by gage.....lb. per sq. in.

(14) Barometric pressure.....in. of mercury

(a) Pressure at boiler, by gage.....lb. per sq. in.

(15) Pressure in 1st receiver, by gage.....lb. per sq. in.

(16) Pressure in 2nd receiver, by gage.....lb. per sq. in.

(17) Pressure in exhaust pipe near engine by gage.....lb. per sq. in.

(18) Vacuum in condenser.....in. of mercury

(a) Corresponding absolute pressure.....lb. per sq. in.

(19) Pressure in jackets and reheaters.....lb. per sq. in.

(20) Temperature of steam near throttle.....deg.

(a) Temperature of saturated steam at throttle pressure.....deg.

(b) Temperature of steam leaving 1st receiver, if superheated.....deg.

(c) Temperature of steam leaving 2nd receiver, if superheated.....deg.

(21) Temperature of steam in exhaust pipe near engine.....deg.

(a) Temperature of injection or circulating water entering condenser.....deg.

(b) Temperature of injection leaving condenser.....deg.

(c) Temperature of air in engine room.....deg.

Quality of Steam

(22) Percentage of moisture in steam near throttle or number of degrees of superheating.....per cent or deg.

Total Quantities

(23) Total water fed to boilers.....lb.

(24) Total condensed steam from surface condenser (corrected for condenser leakage).....lb.

(25) Total dry steam consumed (Item 23 or 24 less moisture in steam)*.....lb.

Hourly Quantities

(26) Total water fed to boilers or drawn from surface condenser per hour.....lb.

(27) Total dry steam consumed for all purposes per hour (Item 25 ÷ Item 12)....lb.

(28) Steam consumed per hour for all purposes foreign to the main engine.....lb.

(29) Dry steam consumed by engine per hour (Item 27 — Item 28).....lb.

(a) Circulating water supplied to condenser per hour.....lb.

Hourly Heat Data

(30) Heat units consumed by engine per hour [Item 29 × (total heat of steam per pound at pressure of Item 13 minus heat in 1 lb. of water at temperature of Item 21)].....B.t.u.

*See footnote Table 6, also first paragraph under "Calculation of Results" ¶ 77a.

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(*a*) Heat converted into work per hour.....B.t.u.
(*b*) Heat rejected to condenser per hour (Item 29*a* ×[Item 21*b*—21*a*l) (approximate).....B.t.u.
(*c*) Heat rejected in form of uncondensed steam withdrawn from cylinders†...B.t.u.
(*d*) Heat lost by radiation.....B.t.u.

Indicator Diagrams

		1st Cyl.	2d. Cyl.	3d Cyl.
(31)	Commercial cut-off in per cent of stroke.....per cent	.....	.....	.....
(32)	Initial pressure above atmosphere.....lb. per sq. in.	.....	.....	.....
(33)	Back pressure at lowest point above or below atmosphere.....lb. per sq. in.	.....	.....	.....
	(*a*) Mean back pressure above atmosphere or zero.....lb. per sq. in.	.....	.....	.....
(34)	Mean effective pressure.....lb. per sq. in.	.....	.....	.....
	(*a*) Equivalent m.e.p. referred to 1st cylinder.....lb. per sq. in.	.....	.....	.....
	(*b*) Equivalent m.e.p. referred to 2nd cylinder.....lb. per sq. in.	.....	.....	.....
	(*c*) Equivalent m.e.p. referred to 3rd cylinder.....lb. per sq. in.	.....	.....	.....
(35)	Aggregate m.e.p. referred to each cylinder.....lb. per sq. in.	.....	.....	.....
(36)	Steam accounted for per i.h.p-hr. at point on expansion line shortly after cut-off.....lb.	.....	.....	.....
(37)	Steam accounted for per i.h.p-hr. at point on expansion line just before release.....lb.	.....	.....	.....
	(*a*) Pressure at selected point near cut-off†.....lb. per sq. in.	.....	.....	.....
	(*b*) Pressure at selected point near release.....lb. per sq. in.	.....	.....	.....
	(*c*) Pressure at point on compression curve shortly after exhaust closure.....lb. per sq. in.	.....	.....	.....
	(*d*) Proportion of direct stroke completed at selected point near cut-off.....	.....	.....	.....
	(*e*) Proportion of direct stroke completed at selected point near release.....	.....	.....	.....
	(*f*) Proportion of return stroke uncompleted at selected point on compression line.....	.....	.....	.....
	(*g*) Ratio of expansion.....	.....	.....	.....
	(*h*) M.e.p. of hypothetical diagram (App. 27).....lb. per sq. in.	.....	.....	.....
	(*i*) Diagram factor (App. 27).....	.....	.....	.....

† In multiple expansion engines.
†Pressures all referred to zero.

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Speed

(38) Revolutions per minute.....r.p.m.
(39) Piston speed per minute.....ft.
  (*a*) Variation of speed between no load and full load.....per cent
  (*b*) Momentary fluctuation of speed on suddenly changing from full load to half load.....per cent

Power

(40) Indicated h.p. developed, whole engine.....i.h.p.
  (*a*) I.h.p. developed by 1st cylinder.....i.h.p.
  (*b*) I.h.p. developed by 2nd cylinder.....i.h.p.
  (*c*) I.h.p. developed by 3rd cylinder.....i.h.p.

(41) Brake h.p.....br. h.p.
(42) Friction of engine (Item 40 — Item 41).....h.p.
  (*a*) Friction expressed in percentage of i.h.p. (Item 42 ÷ Item 40 ×100).....per cent
  (*b*) Indicated h. p. with no load, at normal speed.....i.h.p.

Economy Results

(43) Dry steam consumed by engine per i.h.p-per hr.....lb.
(44) Dry steam consumed by engine per brake h.p-hr.....lb.
(45) Percentage of steam consumed by engine accounted for by indicator at point near cut-off.....per cent
(46) Percentage of steam consumed near release.....per cent
(47) Heat units consumed by engine per i.h.p-hr. (Item 30 ÷ Item 40).....B.t.u.
(48) Heat units consumed by engine per br. h.p-hr. (Item 30 ÷ Item 41).....B.t.u.

Efficiency Results

(49) Thermal efficiency of engine referred to i.h.p. [(2546.5 ÷ Item 47) × 100].....per cent
(50) Thermal efficiency of engine referred to br. h.p. [(2546.5 ÷ Item 48) × 100].....per cent
(51) Efficiency of Rankine cycle between temperatures of Items 20 and 21.....
(52) Rankine cycle ratio referred to i.h.p. (Item 49 ÷ Item 51).....
(53) Rankine cycle ratio referred to br. h.p. (Item 50 ÷ Item 51).....

Work Done per Heat Unit

(54) Net work per B.t.u. consumed by engine (1,980,000 ÷ Item 48).....ft.lb.

Sample Diagrams

(55) Sample diagrams from each cylinder.....
  (*a*) Steam pipe diagrams.

Note:—For an engine driving an electric generator the form should be enlarged to include the electrical data, embracing the average voltage, number of amperes each phase, number

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of watts, number of watt hours, average power factor, etc.; and the economy results based on the electric output embracing the heat units and steam consumed per electric h.p.-hr. and per kw-hr., together with the efficiency of the generator. (See table for Steam Turbine Code, Part VI.)

Likewise, in a marine engine having a shaft dynamometer, the form should include the data obtained from this instrument, in which case the brake h. p. becomes the shaft h. p.

TABLE 10. PRINCIPAL DATA AND RESULTS OF RECIPROCATING ENGINE TEST

(1) Dimensions of cylinders.....
(2) Date.....
(3) Duration.....hr.
(4) Pressure in steam pipe near throttle by gage.....lb. per sq. in.
(5) Pressure in receivers.....lb. per sq. in.
(6) Vacuum in condenser.....in. of mercury
(7) Percentage of moisture in steam near throttle or number of degrees of superheating.....per cent or deg.
(8) Net steam consumed per hour.....lb.
(9) Mean effective pressure in each cylinder.....lb. per sq. in.
(10) Revolutions per minute.....r.p.m.
(11) Indicated horsepower developed.....i.h.p.
(12) Steam consumed per i.h.p-hr.....lb.
(13) Steam accounted for at cut-off each cylinder.....lb.
(14) Heat consumed per i.h.p-hr.....B.t.u.

DATA AND RESULTS OF STEAM TURBINE OR TURBO-GENERATOR TEST

Code of 1915

(1) Test of.....turbine located at.....
To determine.....
Test conducted by.....

Dimensions, Etc.

(2) Type of turbine (impulse, reaction, or combination).....
(*a*) Number of stages.....
(*b*) Condensing or non-condensing.....
(*c*) Diameter of rotors.....
(*d*) Number and type of nozzles.....
(*e*) Area of nozzles.....
(*f*) Type of governor.....

(3) Class of service (electric, pumping, compressor, etc).....
(4) Auxiliaries (steam or electric driven).....
(*a*) Type and make of condensing equipment.....
(*b*) Rated capacity of condensing equipment.....
(*c*) Type of oil pumps (direct or independently driven).....
(*d*) Type of exciter (direct or independently driven).....
(*e*) Type of ventilating fan, if separately driven.....

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(5) Rated capacity of turbine.....
  (a) Name of builders.....

(6) Capacity of generator or other apparatus consuming power of turbine.....

Date and Duration

(7) Date.....
(8) Duration .....hr.

Average Pressures and Temperatures

(9) Pressure in steam pipe near throttle by gage.....lb. per sq. in.
(10) Barometric pressure.....in. of mercury
  (a) Pressure at boiler by gage.....lb. per sq. in.
  (b) Pressure in steam chest by gage.....lb. per sq. in.
  (c) Pressure in various stages.....lb. per sq. in.

(11) Pressure in exhaust pipe near turbine, by gage.....lb. per sq. in.
(12) Vacuum in condenser.....in. of mercury
  (a) Corresponding absolute pressure.....lb. per sq. in.
  (b) Absolute pressure in exhaust chamber of turbine.....lb. per sq. in.

(13) Temperature of steam near throttle.....deg.
  (a) Temperature of saturated steam at throttle pressure.....deg.
  (b) Temperature of steam in various stages, if superheated.....deg.

(14) Temperature of steam in exhaust pipe near turbine.....deg.
  (a) Temperature of circulating water entering condenser.....deg.
  (b) Temperature of circulating water leaving condenser.....deg.
  (c) Temperature of air in turbine room.....deg.

Quality of Steam

(15) Percentage of moisture in steam near throttle, or number of degrees of superheating.....per cent or deg.

Total Quantities

(16) Total water fed to boilers.....lb.
(17) Total condensate from surface condenser (corrected for condenser leakage and leakage of shaft and pump glands).....lb.
(18) Total dry steam consumed (Item 16 or 17 less moisture in steam).....lb.

Hourly Quantities

(19) Total water fed to boilers or drawn from surface condenser per hour.....lb.
(20) Total dry steam consumed for all purposes per hour (Item 18 ÷ Item 8)....lb.
(21) Steam consumed per hour for all purposes foreign to the turbine (including drips and leakage of plant).....lb.
(22) Dry steam consumed by turbine per hour (Item 20 — Item 21).....lb.
  (a) Circulating water supplied to condenser per hour.....lb.

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Hourly Heat Data

(23) Heat units consumed by turbine per hour [Item 22 × (total heat of steam per pound at pressure of Item 9 less heat in 1 lb. of water at temperature of Item 14)]....B.t.u.

(*a*) Heat converted into work per hour....B.t.u.
(*b*) Heat rejected to condenser per hour (Item 22*a* ×[Item 14*b*—Item 14*a*l) (approximate)....B.t.u.
(*c*) Heat rejected in the form of steam withdrawn from the turbine....B.t.u.
(*d*) Heat lost by radiation from turbine, and unaccounted for....B.t.u.

Electrical Data

(24) Average volts, each phase....volts
(25) Average amperes, each phase....amperes
(26) Average kilowatts, first meter....kw.
(27) Average kilowatts, second meter....kw.
(28) Total kilowatts output....kw.
(29) Power factor....
(30) Kilowatts used for excitation, and for separately driven ventilating fan....kw.
(31) Net kilowatt output....kw.

Speed

(32) Revolutions per minute....r.p.m.
(33) Variation of speed between no load and full load....r.p.m.
(34) Momentary fluctuation of speed on suddenly changing from full load to half load....r.p.m.

Power

(35) Brake horsepower, if determined....br. h.p.
(36) Electrical horsepower....e.h.p.

Economy Results

(37) Dry steam consumed by turbine per br. h.p-hr....lb.
(38) Dry steam consumed per net kw-hr....lb.
(39) Heat units consumed by turbine per br. h.p-hr. (Item 23 ÷ Item 35)....B.t.u.
(40) Heat units consumed per net kw-hr....B.t.u.

Efficiency Results

(41) Thermal efficiency of turbine (2546.5 ÷ Item 39) × 100....per cent
(42) Efficiency of Rankine cycle between temperatures of Items 13 and 14..per cent
(43) Rankine cycle ratio (Item 41 ÷ Item 42)....

Work Done per Heat Unit

(44) Net work per B.t.u. consumed by turbine (1,980,000 ÷ Item 39)....ft-lb.

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TABLE 12. PRINCIPAL DATA AND RESULTS OF TURBINE TEST

(1) Dimensions.....
(2) Date.....
(3) Duration.....hr.
(4) Pressure in steam pipe near throttle by gage.....lb. per sq. in.
(5) Vacuum in condenser.....in. of mercury
(6) Percentage of moisture in steam near throttle or number of degrees of superheating.....per cent or deg.
(7) Net steam consumed per hour.....lb.
(8) Revolutions per minute.....r.p.m.
(9) Brake horsepower developed.....br. h.p.
(10) Kw. output.....kw.
(11) Steam consumed per brake h.p-hr.....lb.
(12) Heat consumed per brake h.p-hr.....B.t.u.
(13) Steam consumed per kw-hr.....lb.
(14) Heat consumed per kw-hr.....B.t.u

TABLE 15. DATA AND RESULTS OF STEAM POWER PLANT TEST

Code of 1915

(1) Test of.....plant located at.....
To determine.....
Test conducted by.....

DATE, DURATION, ETC.

(2) Number and kind of boilers (superheaters, if any), engines, turbines, etc.
(3) Rated capcity of boilers in lb. of steam per hour from and at 212 deg. lb.
(*a*) Kind of furnace.....
(*b*) Grate surface.....sq. ft.
(*c*) Percentage of area of openings to area of grate.....per cent
(*d*) Water heating surface.....sq. ft.
(*e*) Superheating surface.....sq. ft.

(4) Rated power of engines or turbines.....
(*a*) Dimensions of cylinders of engine.....
(*b*) Dimensions of turbine.....
(*c*) Type of engines or turbines and class of service.....
(*d*) Name of builders.....

(5) Type of auxiliaries*.....
(*a*) Dimensions of auxiliaries*.....

(6) Type and capacity of condenser.....
(7) Capacity of generators, pumps, or other apparatus consuming power of engine or turbine.....

*For full particulars see text of Report.

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Date, Duration, Etc.

(8) Date.....

(9) Duration. Length of time engine or turbine was in motion with throttle open.....hr.

- (*a*) Length of time engine or turbine was running at normal speed.....hr.
- (*b*) Elapsed time from start to finish.....hr.

(10) Kind and size of coal.....

Average Pressures, Temperatures, Etc.

(11) Boiler pressure by gage.....lb. per sq. in.

- (*a*) Steam pipe pressure near throttle, by gage.....lb. per sq. in
- (*b*) Barometric pressure.....in. of mercury
- (*c*) Steam chest pressure by gage.....lb. per sq. in.
- (*d*) Pressure in receivers and reheaters by gage.....lb. per sq. in.
- (*e*) Pressure in turbine stages by gage.....lb. per sq. in.
- (*f*) Pressure in exhaust pipe near engine or turbine.....lb. per sq. in.

(12) Vacuum in condenser.....in. of mercury

- (*a*) Corresponding absolute pressure.....lb. per sq. in.
- (*b*) Absolute pressure in exhaust chamber.....lb. per sq. in.

(13) Temperature of steam, if superheated (taken at boiler or superheater)....deg.

- (*a*) Temperature of steam, if superheated (taken at throttle).....deg.
- (*b*) Normal temperature of saturated steam at boiler pressure.....deg.
- (*c*) Normal temperature of saturated steam at throttle pressure.....deg.
- (*d*) Temperature of steam leaving receivers, if superheated.....deg.
- (*e*) Temperature of steam in exhaust pipe near engine or turbine.....deg.
- (*f*) Temperature of condensed water in hot-well or feed tank.....deg.
- (*g*) Temperature of circulating water entering condenser.....deg.
- (*h*) Temperature of circulating water leaving condenser.....deg.
- (*i*) Temperature of air in boiler room.....deg.
- (*j*) Temperature of air in engine or turbine room.....deg.

(14) Temperature of feed water entering boilers (average).....deg.

- (*a*) Temperature of each feed supply (if more than one).....deg.
- (*b*) Temperature of feed water entering economizer, if any.....deg.
- (*c*) Increase in temperature of water due to economizer.....deg.

(15) Temperature of escaping gases leaving boiler.....deg.

- (*a*) Temperature of escaping gases leaving economizer.....deg.
- (*b*) Decrease in temperature of gases due to economizer.....deg.
- (*c*) Temperature of furnace.....deg.

(16) Force of draft in main boiler flue.....in. of water

- (*a*) Force of draft at base of chimney.....in. of water
- (*b*) Force of draft at each end of economizer.....in. of water
- (*c*) Force of draft at individual boiler dampers.....in. of water
- (*d*) Force of draft in individual furnaces.....in. of water
- (*e*) Force of draft or blast in individual ash pits*.....in. of water

(17) State of weather.....

- (*a*) Temperature of external air.....deg.

* If artificial draft or blast is employed, the force of draft or blast at the fan should also be given.

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Quality of Steam

(18) Percentage of moisture in steam, or number of degrees superheating.....per cent or deg.

(a) Factor of correction for quality of steam.....

Total Quantities of Coal and Water

(19) Total weight of coal as fired.....lb.

(a) Percentage of moisture in coal.....per cent.
(b) Total weight of dry coal.....lb.
(c) Total ash, clinkers, and refuse (dry).....lb.
(d) Weight of clinkers contained in total ash.....lb.
(e) Percentage of ash and refuse in dry coal.....per cent
(f) Total combustible burned (Item 19*b*—19*c*).....lb.

(20) Total weight of water fed to boiler from all sources†.....lb.

(a) Total water evaporated corrected for quality of steam (Item 20 ×Item 18*a*).....lb.
(b) Factor of evaporation based on average temperature of water entering boiler.....
(c) Total equivalent evaporation from and at 212 degrees (Item 20*a* ×Item 20*b*)..lb.

Hourly Quantities of Coal, Water, and Steam, and Rates

(21) Coal, as fired, per hour (Item 19 ÷Item 9).....lb.

(a) Dry coal per hour (Item 19*b*÷Item 9).....lb.
(b) Dry coal per sq. ft. of grate surface.....lb.

(22) Water evaporated per hour (Item 20 ÷ Item 9).....lb.

(a) Equivalent evaporation per hour from and at 212 deg.....lb.
(b) Equivalent evaporation per sq. ft. of water heating surface.....lb.

(23) Dry steam generated per hour (sum of sub-items *a* to *g*) (Item 20 less moisture in steam ÷ Item 9).....lb.

(a) Moisture formed per hour between boiler and engine.....lb.
(b) Dry steam consumed per hour by engine cylinders or turbine.....lb.
(c) Dry steam consumed per hour by reheaters and jackets, if any.....lb.
(d) Dry steam consumed per hour by air and circulating pump of condenser.....lb.
(e) Dry steam consumed per hour by boiler feed pump.....lb.
(f) Dry steam consumed per hour by other steam driven auxiliaries.....lb.
(g) Dry steam consumed per hour to supply leakage of boilers and piping between boilers and engine (including steam supplied for foreign purposes, if any).....lb
(h) Live steam supplied for heating, or miscellaneous purposes.....lb
(i) Injection or circulating water supplied condenser per hour.....lb

Calorific Value of Coal

(24) Calorific value of 1 lb. of coal as fired, by calorimeter test.....B.t.u.

(a) Calorific value of 1 lb. of dry coal.....B.t.u.
(b) Calorific value of 1 lb. of combustible.....B.t.u.

† If there are a number of supplies of feed water, the weight and temperature of each supply is to be given, and total weight and average temperature ascertained.

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Hourly Heat Data

(25) Heat units in coal as fired generated per hour (Item 21 × Item 24).....B.t.u.

(26) Heat units consumed by engine and auxiliaries per hour (Item 22 × total heat of 1 lb. of steam at pressure of Item 11 less heat in 1 lb. of water at temperature of feed water supplied to boiler, or economizer, if any)....B.t.u.

- (*a*) Heat converted into work per hour.....B.t.u.
- (*b*) Heat rejected to condenser per hour.....B.t.u.
- (*c*) Heat rejected in steam withdrawn from receivers or turbine-stages not used by feed water.....B.t.u.
- (*d*) Heat lost by radiation from engine and auxiliaries, including piping between boilers and condenser B.t.u.
- (*e*) Heat lost in operation of boiler, including economizer, (if any) (Item 25—Item 26).....B.t.u

Indicator Diagrams

(27) Mean effective pressure, each cylinder.....lb.

- (*a*) Commercial cut-off (in per cent of stroke) each cylinder.....per cent
- (*b*) Initial pressure, above atmosphere, each cylinder.....lb. per sq. in.
- (*c*) Back pressure at lowest point above or below atmosphere, each cylinder.....lb. per sq. in.
- (*d*) Steam accounted for per i.h.p. per hour at point near cut-off, each cylinder.....lb.
- (*e*) Steam accounted for per i.h.p. per hour at point near release.....lb.

Electrical Data

(28) Average kilowatt output, gross.....kw.

- (*a*) Volts each phase.....volts
- (*b*) Amperes each phase.....amperes
- (*c*) Kilo-volt-amperes.....kv-a.
- (*d*) Power factor.....

(29) Current used by exciter.....kw.

(30) Net kilowatt output (Item 28 — Item 29).....kw.

Speed

(31) Revolutions per minute.....r.p.m

- (*a*) Variation of speed between no load and full load.....r.p.m.

Power

(32) Indicated horsepower.....i.h.p

(33) Brake horsepower.....br. h.p.

Capacity

(34) Water evaporated per hour from and at 212 degrees (same as Item 22*a*).....lb.

- (*a*) Percentage of rated boiler capacity developed (Item 34 ÷ Item 3 × 100).....per cent

(35) Percentage of rated engine or turbine capacity developed (Item 32 ÷ Item 4 × 100).....per cent

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Economy Results

(36) Coal as fired per i.h.p. of engine per hour.....lb.
(37) Coal as fired per brake h.p. of engine or turbine per hour.....lb.

(*a*) Dry coal per i.h.p. per hr.....lb.
(*b*) Dry coal per brake h.p.-hr.....lb.
(*c*) Dry coal per kw-hr.....lb.

(38) Heat units in coal consumed per i.h.p. of engine per hour.....B.t.u.
(39) Heat units in coal consumed per brake h.p. of engine or turbine per hour (Item 37 × Item 24).....B.t.u.

(*a*) Heat units consumed by engine (including auxiliaries) per i.h.p-hr. B.t.u.
(*b*) Heat units consumed by engine or turbine (including auxiliaries) per brake h.p-hr. (Item 26÷Item 33).....B.t.u.
(*c*) Heat units consumed by engine per kw-hr.....B.t.u.

(40) Heat units in coal consumed per kw-hr.....B.t.u.
(41) Water evaporated per lb. of coal as fired.....lb.

(*a*) Water evaporated per lb. of dry coal.....lb.
(*b*) Equivalent evaporation from and at 212 deg. per lb. of dry coal.....lb.
(*c*) Equivalent evaporation from and at 212 deg. per lb. of combustible.....lb.

(42) Dry steam consumed by engine alone per i.h.p-hr.....lb.

(*a*) Dry steam consumed by auxiliaries per i.h.p-hr.....lb.
(*b*) Dry steam consumed by combined engine and auxiliaries per i.h.p-hr.....lb.

(43) Dry steam consumed by engine or turbine alone per brake h.p-hr.....lb.

(*a*) Dry steam consumed by auxiliaries per brake h.p-hr.....lb.
(*b*) Dry steam consumed by combined engine or turbine and auxiliaries per brake h.p-hr.....lb.

Efficiency Results

(44) Thermal efficiency of plant referred to i.h.p. [(2546.5 ÷ Item 38) × 100].....
(45) Thermal efficiency of plant referred to brake h.p. [(2546.5 ÷ Item 39) × 100].....

(*a*) Efficiency of boilers (Item 41*b* ×970.4 ×100÷Item 24*a*).....
(*b*) Efficiency of engine referred to i.h.p.[(2546.5÷Item 39*a*) ×100].....
(*c*) Efficiency of engine or turbine referred to brake h.p. [(2546.5÷39*b*) ×100].....

Fuel Cost of Power

(46) Cost of coal per ton of ——— lb.....dollars
(47) Cost of coal per i.h.p-hr.....cents
(48) Cost of coal per brake h.p-hr.....cents

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HEAT BALANCE OF STEAM POWER PLANT

	Per lb. coal as fired	Per cent
(49) Heat units in coal (same as Item 24)		
(50) Boiler losses		
(*a*) Loss due to evaporation of moisture in coal		
(*b*) Loss due to heat carried away by steam formed by the burning of hydrogen		
(*c*) Loss due to heat carried away in the dry flue gases		
(*d*) Loss due to carbon monoxide		
(*e*) Loss due to combustible in ash and refuse		
(*f*) Loss due to heating moisture in air		
(*g*) Loss due to unconsumed hydrogen and hydrocarbons, to radiation, and unaccounted for		
(*h*) Heat supplied steam driven appliances for operating boilers less that recovered by heating feed water		
(*i*) Total boiler losses		
(51) Engine consumption		
(*a*) Radiation from steam pipe		
(*b*) Radiation from engine or turbine		
(*c*) Heat rejected to condenser		
(*d*) Heat withdrawn from engine receivers or turbine stages or other use than heating feed water		
(*e*) Heat lost by leakage of steam piping		
(*f*) Heat converted into work		
(52) Heat in steam supplied for purposes foreign to engine or turbine		
Totals (same as Item 49)		
SAMPLE DIAGRAMS		
(53) Sample indicator diagrams from each cylinder of engine. Also sample steam pipe diagrams		
The boiler output, (Item 49—Item 50*i*) may be divided into		
(*a*) Heat units absorbed by water in boiler		
(*b*) Heat units absorbed by water in economizer		
The quantity representing the sum of Items 51*b*, *c*, and *f* may be divided according to the steam distribution into		
(*c*) Heat consumed by engine cylinders or turbine alone (including reheaters or jackets, if any), i. e., total heat supplied to engine or turbine alone less heat recovered therefrom by heating feed water		
(*d*) Heat consumed by steam-driven auxiliaries, i. e., total heat supplied to auxiliaries less heat recovered therefrom by heating feed water		
The same quantity may be divided according to the distribution of work done by engine or turbine into		
(*e*) Heat consumed in supplying power lost in friction of engine or turbine		
(*f*) Heat consumed in supplying frictional, electrical, or other losses of power delivered by engine or turbine shaft		
(*g*) Heat consumed in supplying useful power delivered by engine or turbine, whether mechanical, electrical, or otherwise		

NOTE:—In the case of pumping and air machinery plants add lines under the various items as follows:

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For Item (13)

(*k*) Pressure in delivery main by gage.....lb. per sq. in.
(*l*) Vacuum or pressure in suction main by gage, lb. per sq. in or in. of mercury
(*m*) Correction for difference in elevation of the two gages.....lb. per sq. in.
(*n*) Total head expressed in lb. pressure per sq. in.....lb. per sq. in.
(*o*) Total head expressed in ft.....ft.

For Item (20)

(*d*) Temperature of delivery.....deg.
(*e*) Total weight of water discharged, by measurement.....lb.
(*f*) Total weight of water discharged, by calculation from plunger displacement, corrected.....lb.
(*g*) Total volume of air delivered, by measurement.....cu. ft.
(*h*) Total volume of air delivered reduced to atmospheric pressure and temperature.....cu. ft.

For Item (23)

(*j*) Weight of water discharged per hour, by measurement.....lb.
(*k*) Weight of water discharged per hour, by plunger displacement, corrected.... lb.
(*l*) Volume of water or air delivered per hour, by measurement..... .....cu. ft.
(*m*) Volume of air delivered per hour, reduced to atmospheric pressure and temperature.....cu. ft.

For Item (31)

(*b*) Length of pump stroke.....ft.

For Item (33)

(*a*) Water (or air) h. p.....h. p.

For Item (35)

(*a*) Gal. of water discharged in 24 hr. as measured.....gal.
(*b*) Volume of air delivered per minute, reduced to atmospheric pressure and temperature.....cu. ft.

For Item (36)

(*a*) Dry coal per water (or air) h.p-hr.....lb.

For Item (39)

(*a*) Duty per 1,000,000 B.t.u.....

For Item (45)

(*a*) Thermal efficiency of plant referred to water (or air) h. p.....

For Item (48)

(*a*) Cost of coal per water (or air)h. p.....dollars

TABLE 16. PRINCIPAL DATA AND RESULTS OF STEAM POWER PLANT TEST

(1) Dimensions of boilers.....
(2) Dimensions of engine or turbine.....
(3) Date.....
(4) Duration.....hr.
(5) Boiler pressure.....lb. per sq. in.
(6) Throttle pressure.....lb. per sq. in.
(7) Pressure in receiver or stages.....lb. per sq. in.
(8) Vacuum in condenser.....in. of mercury

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(9) Percentage of moisture in steam near throttle or number of degrees of superheating.....per cent or deg.
(10) Temperature of feed water entering boilers.....deg.
(11) Temperature of escaping gases.....deg.
(12) Force of draft.....in. of water
(13) Coal, as fired, per hour.....lb.
(14) Percentage of moisture in coal.....per cent
(15) Percentage of ash in coal.....per cent
(16) Water evaporated per hour.....lb.
(17) Equivalent evaporation per hour from and at 212 deg.....lb.
(*a*) Equivalent evaporation per hour from and at 212 deg. per sq. ft. water heating surface.....lb.
(18) Steam consumed per hour by engine.....lb.
(19) Steam consumed per hour by engine or turbine and auxiliaries.....lb.
(20) Mean effective pressure in each cylinder of engine.....lb. per sq. in.
(21) Revolutions per minute.....r.p.m.
(22) Indicated horsepower.....i.h.p.
(23) Brake horsepower*.....brake h.p.
(24) Coal as fired per i.h.p-hr.....lb.
(25) Coal as fired per brake h.p-hr.*.....lb.
(26) Steam per i.h.p-hr.....lb.
(27) Steam per brake h.p-hr.*.....lb.
(28) Heat consumed per i.h.p-hr.....B.t.u.
(29) Heat consumed per brake h.p-hr.*.....B.t.u.

TABLE 20. DATA AND RESULTS OF GAS OR OIL ENGINE TEST

From Code of 1915

(1) Test of.....engine, located at.....
To determine.....
Test conducted by.....

Dimensions, Etc.

(2) Type of engine, whether oil or gas.....
(3) Class of engine, (mill, marine, motor for vehicle, pumping, or other).....
(*a*) Number of strokes of piston for one cycle, and class of cycle.....
(*b*) Method of ignition.....
(*c*) Single or double acting.....
(*d*) Arrangement of cylinders.....
(*e*) Vertical or horizontal.....

(4) Rated power.....h.p.
(*a*) Name of builder.....

(5) Number and diameter of working cylinders.....in.
(*a*) Number and diameter of compression cylinders.....in.
(*b*) Diameter of piston rods.....in.

* For pumping engine (water or air) use water or air h. p. in place of brake h. p.

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(6) Stroke of pistons.....ft.
  (a) Compression space referred to piston displacement.....per cent
  (b) Stroke of compression piston.....ft.
  (c) H.p. constant for 1 lb. m.e.p. and 1 r.p.m.....h. p.

Date, Duration, Etc.

(7) Date.....
(8) Duration.....hr.
(9) Kind of oil or gas.....
  (a) Physical properties of oil (specific gravity, burning point, flashing point).....

Average Pressure and Temperature

(10) Pressure of gas near meter.....in. of mercury
  (a) Barometric pressure.....in. of mercury

(11) Temperature of gas near meter.....deg.
  (a) Temperature of cooling water, inlet.....deg.
  (b) Temperature of cooling water, outlet.....deg.
  (c) Temperature of air by dry-bulb thermometer.....deg.
  (d) Temperature of air by wet-bulb thermometer.....deg.
  (e) Temperature of exhaust gases at cylinder.....deg.

Total Quantities

(12) Gas or oil consumed.....cu. ft., lb.
(13) Moisture in gas, in per cent by weight, referred to dry gas.....per cent
(14) Equivalent dry gas at 60 deg. and 30 in.....cu. ft.
  (a) Air supplied.....cu. ft.

(15) Cooling water supplied to jackets.....lb.
  (a) Water or steam fed to cylinder.....lb.

(16) Calorific value of oil per lb., or of dry gas per cu. ft. at 60 deg. and 30 in. by calorimeter test (higher value).....B.t.u.

Hourly Quantities

(17) Gas or oil consumed per hour.....cu. ft., lb.
(18) Equivalent dry gas per hour at 60 deg. and 30 in.....cu. ft.
(19) Cooling water supplied per hour.....lb.
(20) Heat units consumed per hour (Item 16 × Item 18).....B.t.u.

Analysis of Oil

(21) Carbon (C).....per cent
(22) Hydrogen (H).....per cent
(23) Oxygen (O).....per cent
(24) Sulphur (S).....per cent
  (a) Moisture.....per cent
  (b) Result of fractional distillations.....

See note Table 9 for reference to engines driving electric generators and other machinery.

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Analysis of Fuel Gas by Volume

(25) Carbon dioxide (CO_2).....per cent
(26) Carbon monoxide (CO).....per cent
(27) Oxygen (O).....per cent
(28) Hydrogen (H).....per cent
(29) Marsh gas (CH_4).....per cent
(30) Heavy hydrocarbon $C_n H_m$.....per cent
  (*a*) Sulphur dioxide (SO_2).....per cent
  (*b*) Hydrogen sulphide (H_2S).....per cent
  (*c*) Nitrogen (N) by difference.....per cent

Analysis of Exhaust Gases by Volume

(31) Carbon dioxide (CO_2).....per cent
(32) Carbon monoxide (CO).....per cent
(33) Oxygen (O).....per cent
(34) Nitrogen (N).....per cent

Indicator Diagrams

(35) Pressure above atmosphere.....lb. per sq. in.
  (*a*) Maximum pressure.....lb. per sq. in.
  (*b*) Pressure at beginning of stroke.....lb. per sq. in.
  (*c*) Pressure at end of expansion.....lb. per sq. in.
  (*d*) Exhaust pressure at lowest point.....lb. per sq. in.

(36) Mean effective pressure.....lb. per sq. in.

Speed

(37) Revolutions per minute.....r.p.m.
(38) Average number of explosions or firing strokes per minute.....
  (*a*) Variation of speed between no load and full load.....r.p.m.
  (*b*) Momentary fluctuation of speed on suddenly changing from full load to half load.....r.p.m.

Power

(39) Indicated horsepower.....i.h.p.
(40) Brake horsepower.....br. h.p.
(41) Friction horsepower by difference (Item 39 — Item 40)*.....fr. h.p.
  (*a*) Friction horsepower by friction diagrams.....fr. h.p.

(42) Percentage of indicated horsepower lost in friction Item 41.....per cent

Economy Results

(43) Heat units consumed by engine per i.h.p. per hour†.....B.t.u.
(44) Heat units consumed by engine per br-h.p.....B.t.u.

* In two cycle engines this includes the power required for compression.

† If these results, in the case of a gas engine, are based on the low value of the heat of combustion that fact should be so stated.

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(45) Dry gas at 60 deg. and 30 in. consumed per i.h.p-hr.....lb., cu. ft.
(46) Pounds of oil or cubic feet of dry gas per br-h.p-hr.....lb., cu. ft.

Efficiency

(47) Thermal efficiency referred to indicated horsepower.....per cent
(48) Thermal efficiency referred to brake horsepower.....per cent

Work Done per Heat Unit

(49) Net work per B.t.u. consumed (1,980,000 ÷ Item 44).....ft.lb.

HEAT BALANCE

(50) Heat balance, based on B.t.u. per i.h.p. per hour.....

		B. t. u.	Per cent
(*a*)	Heat converted into work	2546.5	
(*b*)	Heat rejected in cooling water		
(*c*)	Heat rejected in the dry exhaust gases		
(*d*)	Heat lost due to moisture formed by burning of hydrogen		
(*e*)	Heat lost in superheating moisture in gas and air		
(*f*)	Heat lost by incomplete combustion		
(*g*)	Heat unaccounted for, including radiation		
(*h*)	Total heat consumed per i.h.p-hr., same as Item 43		

Sample Diagrams

(51) Sample indicator diagrams from each cylinder and if possible a stop-motion light-spring diagram showing inlet and exhaust pressures.....

Note:—For an engine driving an electric generator, the form may be enlarged to include ectrical data in the manner given in the *Steam Turbine Code.*

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MACHINE DESIGN LABORATORY

The outline of the following experiments is representative of the type of laboratory investigations that will be made by the Junior Mechanical Engineering students.

The course is for one credit each semester. Assignments to the experiments will be made one week in advance, when possible, and the student should be acquainted with the general outline of the experiment at hand upon coming to the laboratory.

For suggestions on writing reports, see pages 9 to 14 of this book.

No preliminary report of experiments need be prepared for this course.

Reports are due one week from the date on which the experiment is performed.

Where specific instructions as to method of procedure in making the experiment or for writing up the report of the same are not given in this book, the student will be expected to exercise his judgment and sense of originality, the completed report to represent the efforts of the individual student, or, in some cases, the collective ideas of the group performing the experiment. In this way it is hoped that the originality of the student may be developed along the lines of engineering practice.

The standing of each student will be based on (a) accuracy, (b) practical work in the laboratory, (c) completed report.

NOTE—Fifteen per cent of the credit on each report will be allowed for general form and neatness. Under this head, will be included spelling, grammatical construction of sentences, paragraphing, etc.

Reports that are returned for correction will be corrected by the student and are due one week from date of return.

EXPERIMENT NO. 61

PLATFORM SCALES

The platform scale is one of the most common measuring devices used in engineering work, and probably one of the least understood. This experiment aims to give the student a thorough knowledge of the construction of such scales, an understanding of the errors to

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which it is subject, and a knowledge of the methods of testing and calibrating this device.

The scale beams are so arranged that

$$\frac{d}{c} = \frac{e}{f} \times \frac{g}{c}$$

$$P \times \frac{a}{b} = W \times \frac{d}{c} \therefore \frac{W}{P} = \frac{ac}{bd}$$

The platform scale, Fig. 34, is arranged so that a large weight, W, to be measured, may be balanced by a small weight on the beam, B.

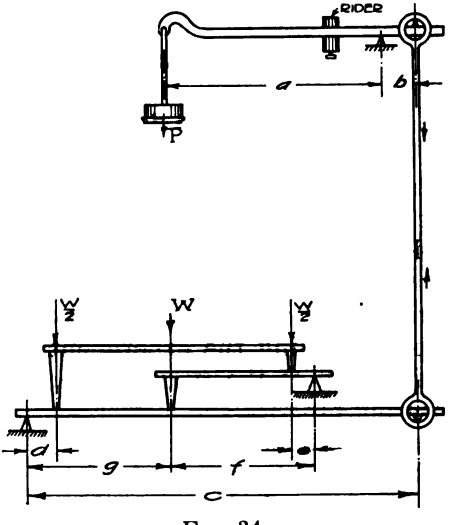

FIG. 34

The rider acts at a variable distance from the beam fulcrum, the beam being graduated to indicate known standard weights.

In your experiment, take the scales apart, carefully measure the different lever arms, noting same upon sketch on your data sheet. Next assemble the scales complete. Then from the measurements on your sketch, calculate if the indicated readings are correct. Note means of adjusting the beam to read zero.

Platform scales are subject to the following errors:

(a) Incorrect weights on scale pan.

(b) Incorrect lever arms due to shifting of knife edges of the lever arms in moving the scales from one place to another.

(c) Scale platform out of level, hence the movements of arms not as designed.

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(d) Load not at center of platform.

For accurate, scientific weighing, scales should be placed on a solid, level foundation and allowed to remain there. It should be calibrated in this position and the load applied at the center of the platform. For commercial purposes, however, scales may be moved about and are so constructed that such moving does not impair their accuracy to any appreciable extent.

Scales are calibrated by placing standard masses upon the platform and noting the reading on the graduated beam at which balance occurs. After calibrating the scales, shift them about roughly and note if there is any change in the calibration.

Place loads at various places on the platform and note if it affects the readings.

Plot the curve showing results of your calibrations, using observed weights as abscissae and standard masses as ordinates.

Experiment No. 62

TEST OF A SCREW JACK

The screw is one of the elementary mechanical movements and one that forms an essential part of a great variety of mechanisms. The efficiency of the screw may be defined as the ratio of the work done by the screw in lifting a given load through a certain height, to the work done upon the screw. This ratio will vary for the various loads lifted. The work done by the screw is the product of the load lifted in lb., and the height through which it is raised. The work done on the screw is the product of the mean force exerted in lb. and the distance passed through by the moving force expressed in any convenient unit.

The screw jack is possibly the best known application of the principles of the screw. By means of this machine, a small force exerted on the end of a lever enables the operator to lift a much greater load on the jack itself.

The load is applied to the jack in the laboratory by a long wooden beam fulcrumed at one end and resting on the head of the jack at a point near the fulcrum. In this way a small load at the end of the beam is multiplied at the jack. It is necessary to determine the dead weight effect on the jack of all parts of the apparatus to be lifted and also the leverage of the long wooden beam by means of which the load is applied.

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To make the experiment, add known weights to the top of the jack. Use a lever of known length, say about 36 in. Connect a spring balance to the end of this lever and pull the lever through an arc of about 90° noting the mean reading on the spring balance. Care must be taken that the pull of the spring balance is always at right angles to the lever. Make this test with six gradually increasing loads with little lubrication on the screw. Repeat them with the screw well oiled. It must be kept in mind, that the weight of the screw and its head must be added to the load lifted in order to determine the total work done by the screw.

The "purchase" of the screw and lever is the ratio of the force on the end of the lever causing motion to the load lifted.

$$K = \frac{T}{W}$$

where K = purchase
T = force on end of lever
W = load lifted by screw.

From the definition given above we can find the efficiency from the formula

$$E = \frac{W \times P}{T \times 2\pi r} \times 100$$

where E = efficiency in per cent
P = pitch
r = arm of lever.

It is assumed that the force acts on the lever for one complete revolution of the screw.

It can be shown by mechanics that the coefficient of friction

$$\mu = \frac{2\pi r \,.\, T \,.\, d - W \,.\, d \,.\, P}{\pi d^2 \,.\, W + 2r \,.\, T \,.\, P}$$

where d = mean diameter of the screw. Ordinary screws and nuts are nonreversible. The pitch angles are very much less than 45° and consequently the efficiency of these screws is often very low. In such cases, however, purchase and nonreversibility are the objects chiefly aimed at.

Explain this nonreversibility of screw.

Plot two curves with efficiency as ordinates and the load on the jack as abscissae, one when the jack is dry and one when it is well lubricated.

Report the tests on the following form:

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TEST OF A SCREW JACK

Made at..... Date.....

Data taken by..... Jack lever {length.....
Observers..... {weight.....

..... Screw cap weight.....

..... Beam {length.....
{weight.....

..... Weight of scale pan.....

Screw {Kind of thread
{Pitch of thread
{Mean diameter
{Weight of screw {dry.....
{oiled.....

Load on jack			Pull on lever	Work done on screw 1-rev. In inch lbs.	Work done by screw 1-rev. In inch lbs.	Efficiency E	Purchase	Coefficient of friction μ
Dead	Live	Total						

EXPERIMENT No. 63

The following method may be employed to obtain the efficiency, work done on the screw, work done by the screw, purchase and coefficient of friction of the jack screw. Place the jack screw to be tested on the center of the table of one of the testing machines in the laboratory. Place a block of hardwood above and below the jack. Balance the poise lever and move the top head of the machine down until in contact with the jack cap. Place the poise at the one thousand pound mark and run the head down until the poise lever is just balanced. Back the screw down and then run it up by means of the lever and spring balance, and note the reading the instant the poise lever rises. Be careful to exert the pull on the lever at right angles to a vertical plane through the lever arm. Now move the poise to the two thousand pound mark, run the movable head down until this load is balanced, and repeat the test. Make six such tests at one thousand pound steps and repeat the observations once or twice under each load.

At each test note the number of full threads exposed to view. In reporting this test, make same assumptions as in Experiment 62 regarding work done on screw.

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Use form as shown for Experiment 62, omitting first two columns headed Dead and Live Load.

Make calculations, etc., as per directions under Experiment 62.

Experiment No. 64

RELATION OF INITIAL TENSION TO EXTERNAL LOAD ON BOLTS

Bolts may be subject to a high tensile stress by screwing up the nuts. A mechanic may rupture the bolt with an ordinary wrench by screwing down the nut too tight. This is especially true of bolts of ½″ diameter or smaller. This experiment is designed to illustrate clearly to the student that it is dangerous practice to use small bolts for screw fastenings, since the actual stress in such bolts depends entirely upon the judgment of the mechanic.

Place the bolt to be tested in a testing machine, so that the axial force upon it may be weighed after it is screwed up. Each student will then screw down the nut as if making a steamtight joint, weighing the resulting load by keeping the beam of the machine balanced. When, in the judgment of the student, the nut is tight, record the load indicated, and then rupture the bolt, taking record of the load at rupture. Repeat this experiment for several of each of the following sizes: ⅜″, ½″, ⅝″, ¾″, and 1″ diameter bolts.

The result of this test may be discordant, since it is dependent upon the judgment of several men, but the general results should indicate that (a) the initial load due to screwing up the nut for a tight joint varies about as the diameter of the bolt; that is, the pull on the wrench is graduated in about that ratio; (b) that the load produced may be estimated to be proportionate to the size of the bolt, or

$$W = Kd$$

in which W = the initial load in pounds, due to screwing up, K is stress in pounds per inch of diameter of bolt and d is outside diameter of screw thread of bolt.

Divide the initial load due to screwing up the nut by the cross-sectional area at the root of the threads to obtain the initial intensity of the stress. This intensity of stress should vary approximately

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inversely as the outside diameter of the bolt, and may frequently equal or exceed *

$$P = \frac{30{,}000}{d} \text{ lbs. per sq. in.}$$

P = intensity of stress.

Plot curves for this experiment, using initial tension as ordinates and breaking loads as abscissae.

Experiment No. 65

STRENGTH OF SCREW THREADS IN CAST IRON

The usual practice in tapping holes in cast iron, is that the hole should be threaded to a depth one and one-half times the outside diameter of the screw, while it is not uncommon for machine tool builders to tap holes to a depth of two diameters. The reason for this is, that the thread of the screw may offer ample frictional resistance against turning when the nut is unscrewed. While this depth of thread is necessary as stated above for frictional resistance, it is far on the safe side considering tensile stress induced in the bolt by either initial or external load, or combination of both.

For purposes of experiment, the student will be furnished with a cast iron block in which there are several sizes of tapped holes. Screw a bolt into the block, allowing the thread to engage two threads. Next apply the load and take your reading just as failure occurs.

Repeat test, engaging three threads, four threads, etc., until the bolt fails other than by stripping out the threads.

Note kind of failure, bolt, or thread; if threaded bolt fits tapped engaged.

Repeat test for several sizes of bolts.

Note kind of failure, bolt, or thread; if threaded bolt fits tapped hole in each case, and any other data that is peculiar to each or any specific test.

In drawing conclusions from this experiment the student is reminded that in order to arrive at any broad decision, a large number of such tests would have to be made, covering the several variables that are liable to occur, such as the quality of the iron in

*See Kimball and Barr, *Elements of Machine Design*, page 169.

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the cast iron blocks, the accuracy of the threads on bolt and in the hole, the material of the bolts, etc.

Plot curve using number of threads entering the block, against the load at which failure occurred.

NOTE—If the quality of iron in blocks is homogeneous and threads accurately cut, the load at which failure occurs should be proportional to the number of threads entering the block. If in your experiment this is not true, try to give reasons why.

EXPERIMENT NO. 66

TESTS OF HOISTING MACHINES

Among the more elementary hoisting machines are the block and tackle, the differential hoist and the triplex hoist. These embody the underlying principles on which the more elaborate hoisting machines are based. This experiment is made to study the efficiency of each of these elementary machines and to determine the conditions under which they will reverse and also their reversed efficiency.

The simplest of these is the rope block and tackle. This consists of two or more pulleys, one or more of which are carried in a frame which is fastened from above to a solid structure and to the lower end of which one end of the rope is fastened. The other pulleys are fastened in a frame which carries the load. The rope is wound alternately over the lower and upper blocks until the remaining end hangs free. This is the end to which the force is applied to move the load.

The differential hoist consists of two pulleys of different diameters fastened in a frame which connects above to the solid structure. The chain passes over the smaller pulley, then down around a pulley in the frame carrying the load and over the large pulley. It is endless and the remaining portion swings free. A force can be applied to one or the other side to raise or lower the load.

The "Triplex" is one of the most efficient of all hoists. The endless chain passing around the hand wheel rotates a shaft on the other end of which is a pinion. The power from this shaft is transmitted by the pinion through a planetary gear system to the "load sheave" around which the chain passes which lifts the load. The gears are so proportioned that the hand chain moves through a large distance when the load is lifted a small distance.

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A hoisting machine in operation has two moving external forces acting upon it. For direct operation, the moving force is called the load and the smaller force, the force applied. For reverse operation, the larger force becomes the force applied and the smaller force, the pull or resistance necessary to balance it. The velocity ratio is the ratio of the travel of the larger force to the travel of the smaller force. The mechanical advantage is the ratio of the larger force to the smaller force. In a frictionless machine the velocity ratio is equal to the reciprocal of the force ratio.

Mechanical efficiency for direct and reversed operation may be expressed by words in a number of ways. In calculated reversed efficiency, the friction loss of the machine is considered equal to the loss in direct operation.

Efficiency may be expressed as equal to

$$(1)\ \frac{\text{Useful work}}{\text{Work expended}}.$$

$$(2)\ \frac{\text{Input} - \text{friction loss}}{\text{Input}}.$$

$$(3)\ \frac{\text{Smaller force for no friction}}{\text{Actual smaller force}}.$$

In considering the different hoists and the forces acting, the following symbols are used:

E_d = Direct efficiency
E_r = Reversed efficiency
W = Larger force on the machine
$P + P_1$ = Actual smaller force on machine
P = Smaller force on machine
P_1 = Smaller force due to friction which is a positive quantity for direct efficiency and a negative quantity for reversed efficiency
D = Shorter travel or arm at which larger force acts
L = Longer travel or arm at which smaller force acts

Using these symbols for direct efficiency the above expressions become,

$$(1)\ E_d = \frac{WD}{(P + P_1)L},$$

$$(2)\ E_d = \frac{(P + P_1)L - P_1 L}{(P + P_1)L},$$

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$$= \frac{PL}{(P+P_1)L},$$

$$(3)\ E_d = \frac{P}{P+P_1}.$$

In determining the efficiencies experimentally the third of these expressions makes the work most simple.

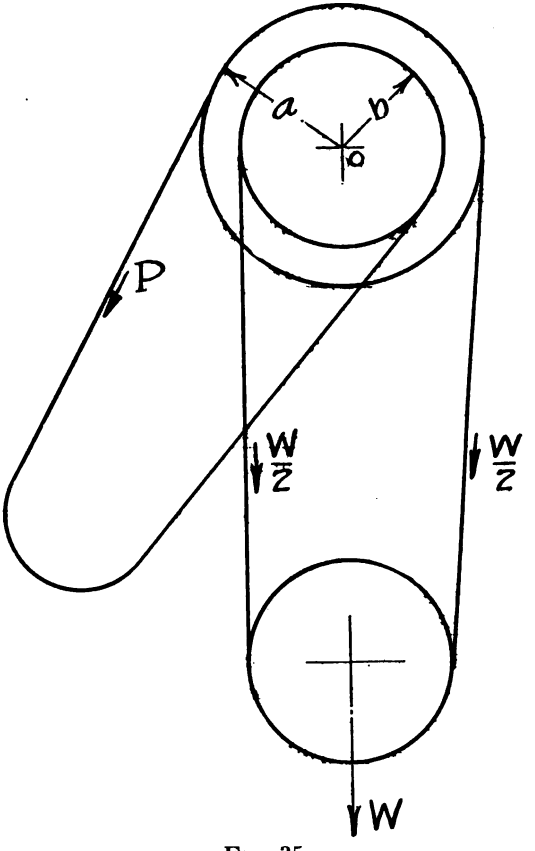

FIG. 35

$$Pa + \frac{W}{2}b - \frac{W}{2}a = o$$

$$Pa + \frac{W}{2}(b-a) = o$$

$$\frac{P}{W} = \frac{a-b}{2a}$$

The tests, therefore, consist of the determination of the velocity ratio of the hoists and a measurement of the work put into the hand chain or rope and that done by the hoist in lifting the load.

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The velocity ratio may be determined on a Weston differential hoist by taking moments about center of the upper pulleys and $\Sigma_m = 0$.

On the other forms of hoists this ratio can be determined experimentally. Tie a piece of string to a link on the load chain opposite some fixed part of the hoist and put a similar piece on the hand chain. Move the former a considerable distance and note the corresponding movement of the hand chain. Repeat several times and calculate the velocity ratio from the mean of the observations.

In performing the experiment deal with each hoist separately. Make a sketch showing the principle of construction and note the range and capacity. Determine the velocity ratio, for this is used to calculate the smaller force P as shown before. With two or three given test loads, find the "actual smaller force on the machine" for direct operation. In testing the rope block and tackle find the "actual smaller force" for about ten loads ranging from a small load to a maximum. Plot an efficiency curve for the block and tackle.

On account of the great friction on starting, the reading of force applied should not be made until the chain has been started by hand. In testing the different hoists notice the conditions under which each will or will not reverse. Note these cases and derive a general law as to when a load will reverse a hoisting machine. See that all hoists are well lubricated before making test.

Report results on the following form:

Plot three curves on one sheet with direct efficiency as ordinates and the load lifted as abscissae, one curve for each hoist.

LOG OF TESTS OF HOISTS

Made at..... Date.....
Observers.....

BLOCK AND TACKLE			DIFFERENTIAL HOIST			TRIPLEX HOIST		
Velocity ratio.	Load.	Pull on rope.	Velocity ratio.	Load.	Pull on hand chain.	Velocity ratio.	Load.	Pull on hand chain.

RESULTS OF TESTS OF HOISTS

Name of hoist.....				
Load lifted, lb. ($P+P_1$).....				
Pull on hand chain, lb. (P).....				
Friction force, lb. (P_1).....				
Direct efficiency (%).....				

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Experiment No. 67

MORIN DYNAMOMETER AND GEAR TRANSMISSION

The Morin Dynamometer is a contrivance for measuring the power transmitted from one source to another. Fig. 3 shows a diagram of the machine.

Upon a shaft resting on two cast iron supports are three pulleys of the same diameter. A is fastened to the shaft and B is loose on the shaft but held otherwise as will be described later.

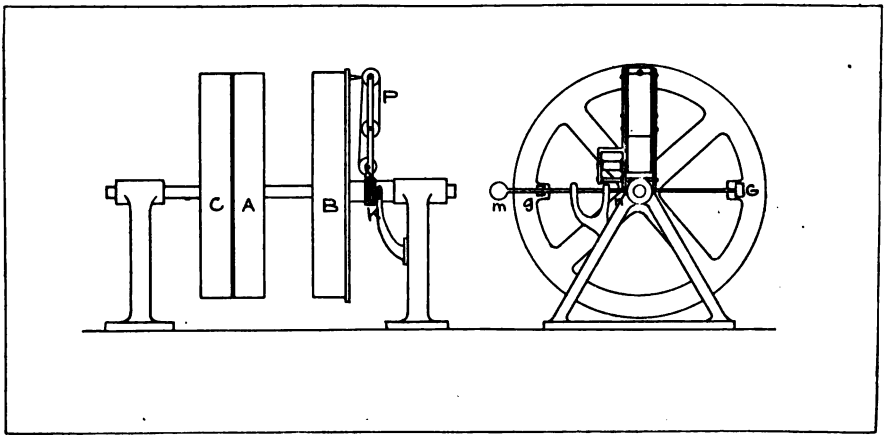

Fig. 36—Morin Dynamometer

This apparatus, in order to measure the power transmitted, must be placed between the driving shaft and the machine whose power requirement is to be measured. C is the loose pulley to which the belt can be shifted when it is desired to stop the dynamometer.

The hub of the pulley B is loose on the shaft but its outer rim at G and g is connected by means of two parabolic springs to the shaft. These springs transmit the turning force to the pulley B and thus to the machine which is being driven. In transmitting this force the springs are deflected more or less according to the load and thus a means is provided by which the power can be measured.

On the shaft there is a worm K provided with a stop so that it may be prevented from revolving with the shaft during the experiment by shifting the arm m n. A series of drums is set in motion by

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a suitably arranged train of gearing from this worm K. By means of this gearing a roll of paper is caused to pass under a pencil P attached to one of the arms of the pulley B. This pencil will record a line whose ordinates measured from some fixed zero base line are proportional to the power transmitted through the shaft. Another pencil is provided which is stationary with regard to the frame carrying the roll of paper. This pencil should be adjusted to draw the zero line which line should coincide with the line traced by the pencil attached to the rim when no load is being transmitted through the dynamometer. When load is placed on the machine the pencil attached to B is deflected and traces a curve whose ordinates are proportional to the power transmitted. The area of the diagram is thus proportional to the power.

To find the value of the ordinates it is necessary to calibrate the dynamometer. This may be done in the following manner. Block the wheel A so that it cannot revolve. Attach a wire cable or rope to some portion of the wheel B and wrap around the circumference. Next fasten a spring balance to the cable and apply a pull of 25 lb. to the balance. The ordinate described by the pencils on the paper is the ordinate equivalent to a force of 25 lb. acting at the circumference of the driving pulley. Move the paper to a new position and find the ordinates for pulls of 50, 75, and 100 lb. successively. Draw a calibration curve with ordinates as abscissae and force applied as ordinates.

As the apparatus is set up in the laboratory, the pulley A is driven by a belt from a motor and the pulley B is belted to the driving shaft of a gear transmission, on the driven shaft of which a Prony brake is mounted. The two levers on the gear transmission can be adjusted so as to give three forward speeds and one reverse speed. Care should be taken not to attempt to change the speed while the gears are in motion.

In this test it is desired to find (a) the power delivered to the driving shaft of the gear transmission which equals 100 per cent minus the percentage of slip of the belt times the power delivered by the dynamometer, (b) the power absorbed by the Prony brake, and (c) the mechanical efficiency of the gear transmission.

Directions for Test

To make a test, fasten paper on the receiving drum and wind off enough to pass over the recording drum and fasten the end firmly to the winding drum. See that the gears of the recording device

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are in perfect order. Adjust the pencils so that they draw legible lines and so that the lines coincide with no load on the dynamometer as for instance when turned by hand.

Calibrate the dynamometer.

Run the dynamometer at speed with the belt off of pulley B. This will represent the friction work of the dynamometer.

Study the gear transmission and find the ratio between the speed of the pulley shaft and the brake shaft with the levers in the positions to give the three forward speeds.

Calculate from the gear ratios what net brake loads at medium and high speeds will produce the same brake horsepower as 50, 100, 150, and 200 lb. on the brake produce at low speed.

Run tests at low, medium, and high speeds with brake loads as calculated above.

During each test take simultaneous readings of the r. p. m. of the dynamometer pulley shaft, the r. p. m. of the driven pulley shaft, the r. p. m. of the brake shaft, the brake load, and a ten second record on the dynamometer.

Find the mean ordinate of the dynamometer record by a planimeter and the results asked for in the sample log.

Plot curves with the mechanical efficiency of the gear transmission as ordinates and the brake horsepower as abscissae (speed constant) and curves with the mechanical efficiency as ordinates and speed as abscissae (brake horsepower constant).

The diameter of the pulley on the Morin dynamometer is 24 in. and the diameter of the pulley driving the gear transmission is 12 in. The length of the brake arm is 21 in.

TEST OF MORIN DYNAMOMETER AND GEAR TRANSMISSION

Made at..... Date.....
Length of brake arm, ft..... Radius of dynamometer pulley.....
Weight of brake arm, lb..... Radius of gear driving pulley.....
Observers.....

Time	Speed ratio	Dynamometer			Gear Transmission				% creep of the belt	H. P. delivered to gear	Mech. efficiency
		r. p. m.	Pounds at radius of pulley	Dyn. H. P.	r. p. m. of driving shaft	r. p. m. of brake shaft	Net brake load, lbs.	Brake H. P.			

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EXPERIMENT NO. 68

ABSORPTION DYNAMOMETERS—THE PRONY BRAKE

Machines for the measurement of power may be divided into two general classes: those which absorb the power measured, called absorption dynamometers, and those which form a connecting link in the transmission of the power to be measured, called transmission dynamometers.

The form of absorption-dynamometer in most common use is the Prony brake, of which there are many varieties. One of the simplest forms is shown in figure 4. This brake consists of a band wrapped around a pulley which receives the power to be measured. The band is provided with adjustable weights, and the friction induced by the revolution of the pulley is such as to sustain the weighted end of the band against gravity. An increase in load is obtained by adding more weights which causes the band to bear against the wheel with greater force, thus increasing the friction.

Since it is difficult to obtain the weight which will just be thus sustained, it is customary to attach a spring balance to the other end of the rope as a compensating device. The lower end of the balance is attached to the floor.

The power absorbed by such a brake is given by the formula

$$\text{H. P} = \frac{2\pi rn\,(W-w)}{33000}$$

r being the radius of the wheel; + half the thickness of the band (if rope is used it is half the diameter of the rope).

n is the revolutions of the wheel per minute or r. p. m.

W is the weight on the tight side of the band.

w is the weight on the slack side of the band indicated on the spring balance.

The Prony Brakes of the Engineering Laboratory consist of a band wrapped around the pulley of the engine whose power is to be measured, so arranged that by tightening a hand wheel, the friction between the wheel and the band can be controlled. The band is held from turning with the wheel by means of an arm attached to it and supported at its free end by some measuring device such as a platform scales.

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Considering the friction between the band and wheel as a single force, f, then the power developed, measured in horsepower, is

$$\text{H.P.} = \frac{2\pi\, rfn}{33000}$$

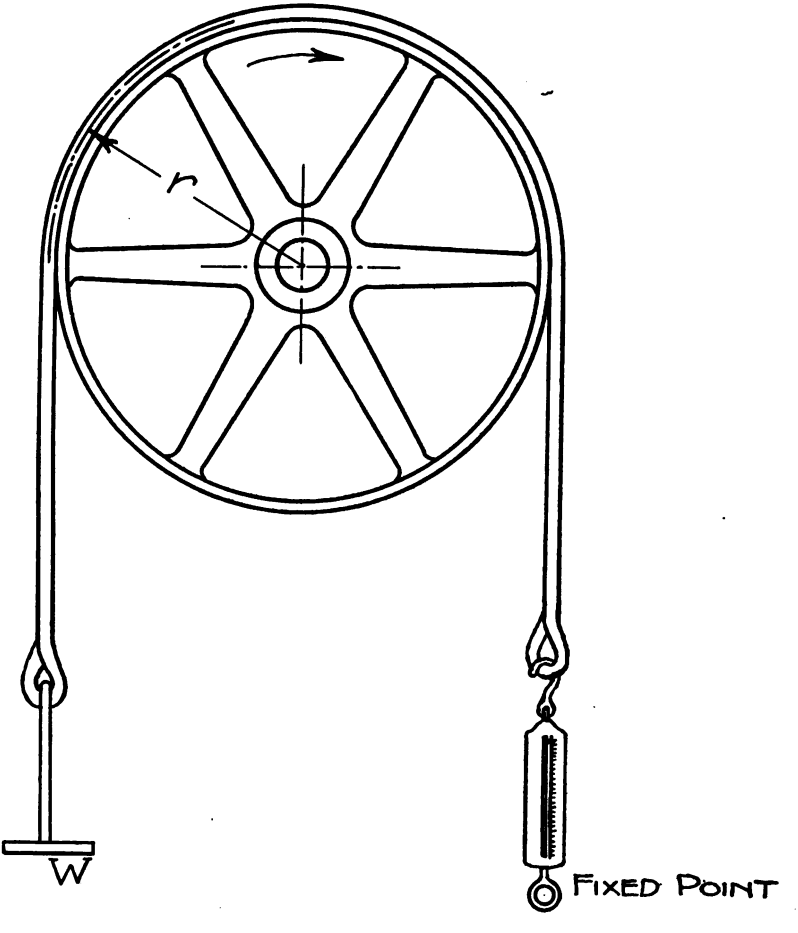

FIG. 37

Now since the force W exerted on the scales produces equilibrium, by the principle of moments

$$RW = rf$$

R = length of brake arm measured from the center of the brake wheel to the point bearing on scale platform.

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r = radius of brake wheel in feet

and substituting in the expression for horsepower above

$$\text{H.P.} = \frac{2\pi \text{ R.WN}}{33000} = \text{BWN}$$

B being the "brake constant" for the particular brake calibrated.

In making this experiment, the weight of the arm itself produces a force acting on the scales which must not be included in the force balancing the frictional effort. Allow for this correction by determining the unbalanced weight of the brake and subtracting it from the scale readings.

Report on form as follows:

TEST OF PRONY BRAKE ON.....ENGINE

Made at..... Date.....
Date taken by..... Length of brake arm in feet.....
Observers..... Weight of brake arm in lbs.....

Time	r. p. m.	Brake load	Brake H. P.	Brake constant

EXPERIMENT No. 69

TEST OF A BELT

TRANSMISSION DYNAMOMETER

It is often desirable to know the amount of power being transmitted by a given sized belt and also to compare the transmitting power of different belts with different initial tensions in each. Again at times it is desirable to know the coefficient of friction between the belt and the pulley over which it passes and how this friction may be increased by various belt dressings. All such information may be had by running tests on the given belts under the desired conditions on a machine constructed for such work.

In the laboratory, the belt testing machine is driven by a motor whose speed can be varied by varying the resistance of its fields. This motor drives a pulley which is connected by a universal coupling to another shaft carrying a pulley. This second shaft is

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mounted in a frame provided with an arm and is so suspended that any horizontal tension on a belt placed on this pulley produces a corresponding reading on scales placed under the arm. The pulley serves as the driving pulley for the belt under test and drives another pulley which is fastened to a shaft carrying a brake wheel. The frame carrying this last mentioned shaft is fastened solidly to the base of the machine but provision is made whereby the initial

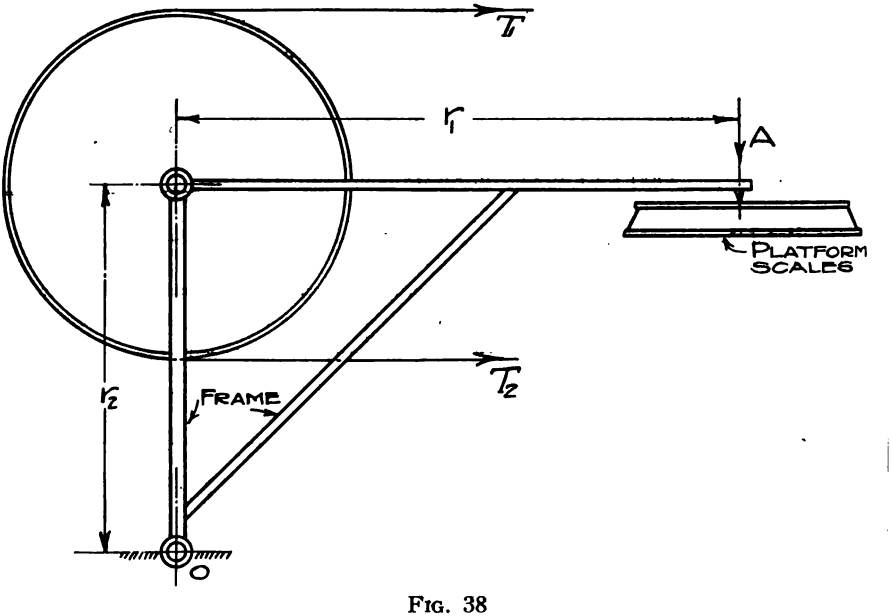

FIG. 38

tension in the belt can be varied by shifting the bearings in suitable guides on this frame.

DIRECTIONS FOR TEST

The total tension in the belt can be found by taking moments about the point O, Fig. 38, and $\Sigma_m = 0$

$$T_1 + T_2 = \frac{Ar_1}{r_2},$$

where T_1 = the tension on the tight side of the belt
T_2 = the tension on the slack side of the belt
A = net weight on the scales in pounds

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r_1 = arm from center of shaft to knife-edge in feet

r_2 = distance from the center of shaft (in feet) to center of suspension of the frame

With a load on the brake the difference of tension which is proportional to the power transmitted is found by taking moments about the center of the driven pulley Fig. 39 and $\Sigma_m = 0$

$$T_1 - T_2 = \frac{Br_3}{r_4},$$

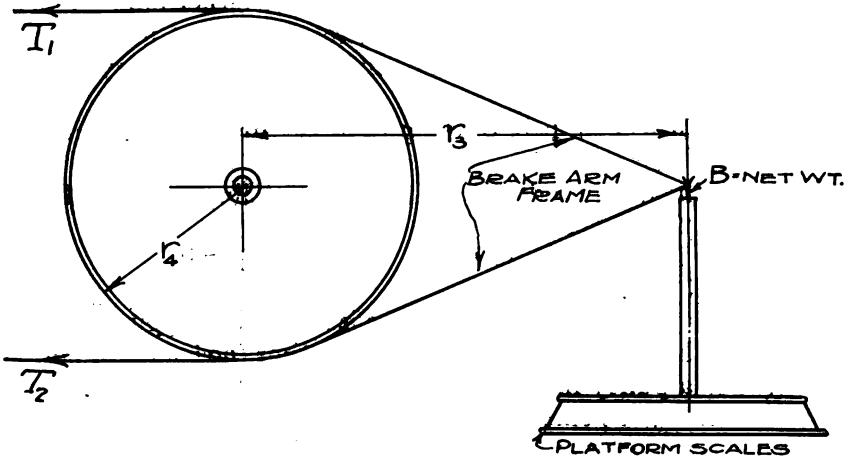

FIG. 39

where B = net weight on the brake scales in pounds

r_3 = arm of brake in feet = ... ft.

r_4 = radius of driven pulley in feet = ... ft.

The power delivered can be found as follows:

$$P \text{ (in H. P.)} = \frac{2\pi r_3 \cdot B \cdot N_2}{33000}$$

where N_2 = number of revolutions per minute of driven pulley.

From Mechanics we find that the coefficient of friction

$$f = \frac{\log \frac{T_1}{T_2}}{0.434\,M}$$

where M = arc of contact in inches divided by radius of pulley in inches.

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Although there may be no actual slipping as a whole between the belt and its pulleys, yet the unequal stretching of the two parts of the belt due to the unequal tensions T_1 and T_2 cause a difference in angular velocity ratio which becomes very serious when this is required to be kept uniform.

Any elastic material subjected to tension becomes elongated and the elongation depends directly on the stretching force. Hence the belt will be stretched to a greater extent on the driving side than on the slack side.

Let L = length in feet of belt which would leave either pulley in unit time if the belt were unstretchable and inelastic

l_1 = length in feet of belt running onto the driving pulley in unit time

l_2 = length in feet of belt running onto the driven pulley in unit time

E = the elongation produced by tension of 1 lb. on a length of 1 ft. of belting

Then $l_1 = L + E\ T_1\ L = (1 + E\ T_1)\ L$

and $l_2 = (1 + E\ T_2)\ L$

Since it has been supposed that there is no actual slipping between the belt and the pulley as a whole, it is clear that the length of belting coming onto a pulley in unit time will be equal to the length of the arc described by a point on the circumference of the pulley in the same time. In other words the length of belting coming onto a pulley in unit time is equal to the circumferential speed of the pulley. Hence for the driving pulley

$$l_1 = 2\pi r_5 . N_1$$

where r_5 = radius of driving pulley in feet = ...ft.

and N_1 = number of revolutions

and for the driven pulley

$$l_2 = 2\pi r_4 . N_2$$

where N_2 = number of revolutions of driven pulley

Therefore

$$\frac{2\pi r_4\ N_2}{2\pi r_5\ N_1} = \frac{r_4 N_2}{r_5 N_1} = \frac{l_2}{l_1} = \frac{(1 + ET_2)\ L}{(1 + ET_1)\ L},$$

or

$$\frac{1 + ET_2}{1 + ET_1} = \frac{r_4 N_2}{r_5 N_1}.$$

This factor is always less than unity and varies with varying conditions in the belt. The loss of velocity in the driven pulley is

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known as the "slip" or "creep" due to elasticity. Were the belt of inelastic material this loss would be avoided. On account of this loss, belts are unsuitable for trains of gearing where fixed velocity ratios are imperative.

The percentage of creep equals $100\% - \frac{r_4 N_2}{r_5 N_1}$

To make a test of a belt proceed as follows:

Find the dead weight on each scale.

Calculate at what loads the tension scale should balance to produce initial tensions of 20, 40, 60, and 80 lb. per in. width of belt.

Put the belt on and while the pulleys are at rest adjust the distance between the centers of pulleys until there is an initial tension of 20 lb. per in. width of belt.

Bring the motor up to speed, and, keeping the speed constant, run several tests, beginning with ..... lb. on the brake and gradually increasing the brake load until the belt begins to slip on the pulley.

Repeat for initial tensions of 40, 60, and 80 lb. per in. width of belt. The apparatus must be stopped between each series to adjust for a new initial tension.

During each test take simultaneous readings of the r. p. m. of the two pulley shafts, the brake load, and the tension scale.

Find the results asked for in the following forms and plot on one sheet curves with the creep as ordinates and the brake horsepower as abscissae for each initial tension.

Draw a curve with initial tension as abscissae and the maximum brake horsepower as ordinates.

Report as per following forms:

Form 1 TEST OF BELTING

Made at..... Date.....
Description of belt.....
Material..... Made by.....
Length.....ft. width.....in. Thickness.....in.
Condition..... Dead weight on brake.....
Observers..... Arm of brake.....

Time	Initial tension	r. p. m. driving pulley	r. p. m. driven pulley	Brake reading lb.	Tension reading lb.	T_1+T_2	T_1-T_2	T_1	T_2	Ratio $\frac{T_1}{T_2}$	Arc of contact	Coefficient of friction	Slip or creep	Brake H. P.

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Form 2 TEST OF BELTING

General Report

Made at..... Date.....
Description of belt.....
Material..... Made by.....
Length.....ft. width.....in. Thickness.....in.
Condition..... Observers.....

CONSTANTS OF MACHINE

Diameter of driving pulley, in..... Diameter of driven pulley, in.....
Width of face driving pulley, in..... Width of face driven pulley, in.....
Horizontal arm of tension scales, ft..... Vertical arm of tension scales, ft.....
Arm of Prony brake, ft.....

1.	Duration of trial.....			
2.	Revolutions driving shaft.....			
3.	Revolutions driven shaft.....			
4.	Belt speed, feet per min.....			
5.	Brake scales, lb.....			
6.	Tension scales, lb.....			
7.	Circumference driving pulley, ft.....			
8.	Circumference driven pulley, ft.....			
9.	Brake horsepower.....			
10.	Slip of belt, per cent.....			
11.	Slip of belt, ft. per min.....			
12.	Horsepower per inch of width.....			
13.	Maximum tension, T_1.....			
14.	Minimum tension, T_2.....			
15.	$T_1 - T_2$.....			
16.	$T_1 + T_2$.....			
17.	Arc of contact, degrees.....			
18.	Coefficient of friction, per cent.....			

EXPERIMENT NO. 70

TRANSMISSION DYNAMOMETER EXPERIMENT

A form of transmission dynamometer which may be easily and cheaply constructed is shown in Fig. 40.

The torque of the transmission shaft is equal to the effective belt pull, $T_1 - T_2$ multiplied by the radius r at which it acts.

Neglecting friction at the pulley bearings P_1 and P_2 the reactions at these bearings will be $2T_1$ and $2T_2$ at each bearing respectively.

Taking moments about the fulcrum f, and disregarding the weight of the arm A we have

$$WR + 2T_2 a = 2T_1 a$$

transposing $T_1 - T_2 = \frac{WR}{2a}$

and the torque $= r(T_1 - T_2) = \frac{rWR}{2a}$

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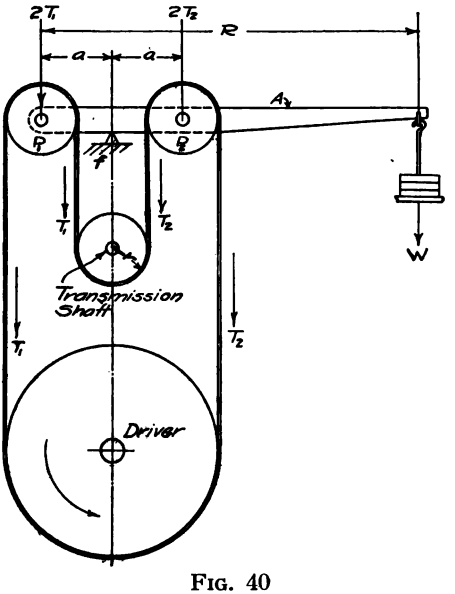

FIG. 40

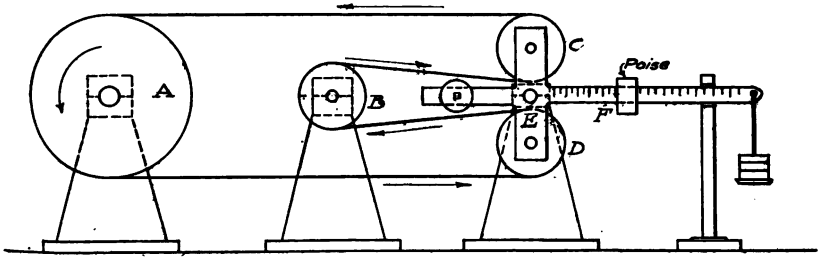

FIG. 41

In reporting this test use the general form outlined in Experiment 69.

Another form which is useful for mill purposes is the belt dynamometer, the principle of which is shown in Fig. 41. *A* is the driving pulley and *B* the driven pulley. The connecting belt passes over the dynamometer pulleys *C* and *D*. These two pulleys are mounted on a frame carrying a scale beam *F*, all of which turn on the center *E*. The difference in the total strain on the two sides of the belt is computed by multiplying the net weight on the beam by the leverage, the latter being found by dividing the length of the beam by the distance from the center *E* to the centers of pulleys *C* and *D*.

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EXPERIMENT NO. 71

FRICTION IN BEARINGS

The friction developed in a bearing may be due to either of several causes. The surfaces in contact may be so rough that abrasion may occur, or the weight on the journal may be carried wholly by a few high spots on the bearings. The lubricant may be unsatisfactory for the conditions, may not be properly applied to the bearings, or may not be supplied in sufficient quantity. The weight on the bearings may be so great that the lubricant is prevented from getting between the rubbing surfaces and hence great friction is developed. The presence of dirt in a bearing will also cause trouble and heating.

The friction due to uneven surfaces may be overcome by carefully fitting the bearings and journal before putting them into service. A lubricant should be used which is suitable for the work in hand. The maximum pressure to be carried on the bearing should be considered in the design and allowance made for it. Careful cleaning of the bearing in assembling and afterwards protecting it from dust and dirt will avoid troubles from friction. All lubricants should be free from dirt and grit.

Friction in bearings is usually determined by means of one of the standard oil testing machines. The apparatus consists of a short cylindrical axle overhanging from a shaft which is supported by two bearings with cone pulleys between them. Fitted on this overhanging journal is a pendulum carrying the bearing on which the test is to be made. The bearing is made in halves. It is so arranged that any given pressure can be exerted on both halves by means of an adjusting screw which acts on a coil spring carried in the pendulum itself. The front of the pendulum carries a scale on which the pressure exerted on the bearing by the spring can be read directly. A thermometer placed in the upper half of the bearing gives its temperature during test.

The pendulum carries a large ball on top which partially counterbalances the weight of the lower portion and thus increases its sensitiveness.

The deviation of the pendulum from the vertical is shown on a graduated arc which reads the actual friction. This reading

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divided by the total pressure shown on the other scale gives the coefficient of friction for the bearing.

Theory of Oil Testing Machines

The mathematical formulas applying to these machines are as follows: Let P be the total pressure on the journal, p be the pressure per sq. in. on the projected area of the journal, T the tension of the spring, W_1 the total weight of the pendulum, r the radius of the journal, R the effective arm of the pendulum, θ the angle of the deviation of the pendulum from a vertical position, F the total force of friction and f the coefficient of friction, l the length of the bearing surface of each half of the bearing.

Since in this machine each half of the bearing is loaded the projected area of this bearing surface is 2 (2r) l or 4r l.

The total load on the journal is

$$P = 2T + W_1.$$

Hence

$$p = \frac{P}{4lr} = \frac{2T + W_1}{4lr}.$$

By definition

$$f = \frac{F}{P}.$$

Since the moment of friction is equal to the external moment of forces acting,

$$F r = P f r = f (2T + W_1) r = W_2 R \sin \theta$$

for the friction has swung the unbalanced weight of the pendulum W_2 thru the angle θ.

From which

$$f = \frac{F}{P} = \frac{W_2 R \sin \theta}{rp}$$

In friction testing machines $\frac{W_2 R \sin \theta}{r}$ is usually shown on a fixed scale on which the graduations vary as sin θ, for $\frac{W_2 R}{r}$ is a constant for any given machine.

When the pendulum is not free to move but has a horizontal arm resting on a knife-edge on platform scales, the moment of the force on the scales replaces $W_2 R \sin \theta$, and the formula becomes

$$f = \frac{F}{P} = \frac{W' R'}{rP}$$

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where W′ is the pressure on the scales and R′ the arm to the knife-edge.

As the constants of the machine are likely to change with use, they should be determined before every test, and the final results corrected accordingly. The constants may be found as follows:

With free pendulum, to determine the constant W_2R, swing the pendulum to a horizontal position as determined by a spirit level. Support it in this position by a strut carrying a knife-edge and resting on platform scales. From the weight of the pendulum corrected for weight of strut, and from the length of arm from knife-edge to center of journal, the value of W_2R can be found. This test should be repeated at several points along the pendulum and the average of the products taken for the value of W_2R.

Obtain the weight of the pendulum itself by removing it and carefully weighing it.

Measure the length and radius of the journal and compute the projected bearing surface 2 (2lr). Compute the constant $\frac{W_2R}{r}$ and by setting the pendulum at various angles note whether the value on the graduated scale is correct. Plot a correction curve for these readings.

When preparing to determine the coefficient of friction by this machine, see that both halves of the bearing are perfectly clean and in good shape. Also examine the journal. If the oil is to be changed, clean the bearing and journal with alkali or benzine, to remove all traces of any oils formerly used. Assemble the pendulum on the journal and screw in the holding nut with its washer.

See that the oil feed arrangement works properly. Belt up the machine for the high speed and throw on the power, at the same time supplying oil at a rate calculated to maintain a free supply. Gradually tighten the nut under the spring until the tension indicates 50 pounds per sq. in. In the tests, the loads, velocities, etc., are kept constant and if the bearing is flooded with oil it will be possible to keep the temperature constant also.

Make tests at 50, 100, 150, and 200 lb. per sq. in. on the bearing. Read the arc of deflection, the temperature of the bearing, the amount of oil used, and the speed.

Count the drops of oil to the bearing to determine the relative rate of flow.

If possible make a series of runs with constant pressure and variable speed.

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In your report describe the object of the test, the apparatus used, and the method of obtaining results.

Tabulate observed data as per accompanying form.

Draw a series of curves showing results of the various tests as follows:

(1) With total friction as abscissae and pressure per sq. in. as ordinates, for constant speed.

(2) With coefficient of friction as abscissae and pressure per sq. in. as ordinates, for constant speed.

(3) With coefficient of friction as abscissae and velocity of rubbing faces in feet per min. as ordinates, for constant pressure.

Form 1 LOG OF FRICTION IN BEARINGS

Name of lubricant..... Bearing metal.....
Journal..... Moment of pendulum.....
Bearing surface, length..... Width.....Area.....
Date..... Observers.....

Time	r. p. m.	Temperature of journal	Total pressure on journal	Total friction	Coefficient of friction	Time	r. p. m.	Temperature of journal	Total pressure on journal	Total friction	Coefficient of friction

Form 2 FRICTION IN BEARING—GENERAL DATA

Name of lubricant.....
Bearing metal..... Journal..... Diam.....
Bearing surface, length..... Width..... Area.....
Moment of pendulum.....
Date..... Observers.....

1.	Test No.....			
2.	Pressure on journal, lb. total.....			
3.	Pressure on journal, lb. per sq. in.....			
4.	Method of lubrication.....			
5.	Minimum coefficient of friction.....			
6.	Maximum temp. of journal.....			
7.	Temperature of room.....			
8.	Rise of journal temp. above room.....			
9.	Revolutions per min. of journal.....			
10.	Feet traveled by rubbing surface per min.....			
11.	Pressure per sq. in. × feet traveled per min.....			

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Experiment No. 72

TEST OF COMMERCIAL BEARINGS

The apparatus for this experiment is located on the balcony at the west end of the laboratory and consists of five lengths of $2\frac{7}{16}$ in. cold rolled shafting, connected together with flexible leather couplings and supported by ten shaft hangers bolted to I beams. A seven horse power direct current shunt motor is coupled to this series of shafts and can be equipped with instruments for reading voltage, field current, and armature current. Each section of shaft has two intermediate bearings supporting two levers for applying load to the bearings. One end of each lever is held in place by a fulcrum while the other end supports a second lever. The load is applied to the second lever by means of a jackscrew placed upon a platform scales. By raising or lowering the head of the jackscrew, loads may be applied to the bearings and weighed by the scales. The scales records the load on *both* of the intermediate bearings.

While each section of shaft has four bearings on it, only one side of each bearing is subject to pressure on the shaft, thereby creating the same conditions as exist on the ordinary line shaft in shop practice. The motor can be connected to two 110 volt circuits in series, and by means of suitable resistance in series with the armature, speeds varying from 150 to 450 r. p. m. can be obtained. The field current is kept constant for all tests.

The apparatus is so constructed that hangers and bearings of any make can be attached and comparative tests made as to the power required to run the different bearings under the same conditions of load and speed.

Method of Conducting the Tests

Start the motor and by varying the resistance of the armature circuit, run the shaft at 150, 250, 350, or 450 r. p. m. as designated by instructor. Keep the speed constant and run 6 twenty-minute tests with load on the scales of 50 lb., 80 lb., 110 lb., 140 lb., 170 lb., successively. Take readings of time r. p. m. load on scales, volts, field amperes, armature amperes, and temperature of bearings if possible.

At the end of the test disconnect the motor from the shaft and make a ten minute test at the same speed to find the friction load of

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the motor. In figuring the work lost in friction per bearing this motor friction load should be subtracted from your power readings taken during the test.

Volts x amps. = watts.

746 watts = 1 H. P. = 33,000 ft. lb. per min.

General Information

Size of the shaft $2\frac{7}{16}$ in.

Scales No.	1	2	3	4	5
Dead weight on scales	43.5 lb.	42.5 lb.	41.5 lb.	42 lb.	44 lb.

Total load on each bearing due to dead load of the levers including the weight of the bearing is 422 pounds.

One pound of live load supplied at scales through jackscrew = 8.33 lb. applied at bearing.

There are 20 bearings on the shaft.

$$\text{Coefficient of friction} - U = \frac{12\,W}{P\,d\,N\,\pi}$$

where U = coefficient of friction.
W = work lost in friction in foot pounds per bearing.
P = total pressure on bearing pounds.
d = diameter of bearing in inches.
N = r. p. m.

Data and Curves

Figure W and U for each different load.

Figure the load on each bearing for different loads on scales.

Figure the load per square inch of the projected area of the bearing for each load. (If ball bearings are tested this item need not be figured.)

Curves

Plot a curve with pressure per sq. in. as abscissae and power loss as ordinates.

Plot a curve with pressure per sq. in. as abscissae and coefficient of friction as ordinates.

(If ball bearings are tested, plot the total pressure as abscissae instead of pressure per sq. in.)

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TEST OF BEARINGS

Kind of bearings..... Make of bearings.....
Size..... Date.....
Observers.....

Time	r. p. m	Field current	Armature current	Volts	Load on scales	Room temp	BEARING TEMPERATURES				

EXPERIMENT NO. 73

STRENGTH OF BELTS AND BELT FASTENINGS

It is of considerable interest to the engineer to know just what the ratio of working stress to ultimate strength of different kinds of belting and belt fastenings. The student must keep in mind however that belts stressed in actual running over pulleys are also subject to the bending action in going over the pulley and this bending is considerable when belts run over small pulleys. Actual conditions cannot be obtained without the use of complicated apparatus, so for the purpose of this test we will use a testing machine and two stationary pulleys—the object of the experiment being to get data on tensile strength of the belt and to compare the strength of the fastening with the strength of the solid section of the belt.

In making this test place one pulley frame in the upper head and the second pulley in the lower head of the machine. Fasten in the piece of belt to be tested and test the belt for the tensile strength of the material.

Test the holding power of the following fastenings:

(a) Factory joint (glued joint)
(b) Raw hide, single laced
(c) Raw hide, double laced
(d) "Peerless" wire fastening
(e) "Clipper" wire fastening
(f) "Alligator" steel fastening
(g) Other types of steel fastenings

Make out a table giving the tabulated data of this experiment as follows:

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	Kind of joint	Kind of Belting								Remarks
		Leather		Canvas		Balata		Rubber		
		I	II	I	II	I	II	I	II	
Stretch in 4"										
Load breaking										
Kind of failure										
Efficiency %										
Stretch in 4"										
Load breaking										
Kind of failure										
Efficiency %										
Stretch in 4"										
Load breaking										
Kind of failure										
Efficiency %										
Stretch in 4"										
Load breaking										
Kind of failure										
Dimensions										
Stretch in 4"										
Load breaking										
Kind of failure										
Efficiency %										

The student will refer to similar tests made by Prof. Benjamin. See Benjamin's *Machine Design.*

See results of tests made at U. W. laboratory by A. H. Miller. *American Machinist, Vol. 37, p. 609.*

Experiment No. 74

TEST OF HELICAL SPRINGS

Helical springs are designated to resist actions which tend to extend, shorten or twist the spring relatively to its longitudinal axis.

For the experiment in the laboratory, a nest of springs such as is used to absorb the shocks of a railway freight car will be tested. The particular kind of spring used is known as a M. C. B. standard 60,000 lb. car spring (See *Master Car Builders Dictionary* for specifications).

Place nest of springs in a testing machine and balance the beam.

Measure "free height" of spring.

Use loading increments of 1,000 lbs. and read deflection, recording same.

Load until spring goes solid.

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Next test each spring separately, using proportionate increments of loading for each. Load until springs go solid.

Since the ends of the wire of "compression" springs are usually flattened to secure better bearing seats, allowance must be made for this in considering the number of coils that are under stress.

Calculate the length of wire in each spring, and "solid" height of each spring from the number of coils.

Why is the wire of the smaller spring subjected to a higher working stress than the larger wire of the outer spring?

The form used for this test is as follows:

Made at..... (Make a sketch showing all dimensions
Data by..... of each spring.)
Observers.....
Date.....

Load in lbs.	Height in inches	Deflection in inches	Increment of deflection inches	Unit stress induced in wire, lbs. per sq. in.	Modulus of elasticity	Energy absorbed or given out in lbs.

Take readings while loading spring and also while unloading spring.

Does expression on page 135 *Elements of Machine Design*, Kimball and Barr) hold for this experiment:

$$p = 40000 + \frac{15000}{d}$$

p = fibre stress d = diam. of wire

Plot three curves, one the load-deflection curve for loading, one for unloading, and the third for energy expended.

Compare your results with those reported in Vol. V, page 173, *A. S. M. E. Transactions.*

Explain high unit fibre stresses.

(For formula for Helical Springs see *Elements of Machine Design* by Kimball and Barr.)

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Experiment No. 75

TEST OF FLAT PLATE SPRINGS

Flat springs are cantilevers or beams. For practical purposes these springs are built up of several layers, or plates, called leaves, the result being a laminated spring. Such springs approximate a beam of uniform strength in form. Two or more springs may be compounded as in the three quarter or full elliptical springs used under automobiles, wagons, etc., and when this is done, each spring is computed separately, the total deflection being the sum of the deflections for separate springs of the set.

In using formula, consult the rules I, II, and III, as is stated in *Elements of Machine Design:* Kimball and Barr, page 127.

The form used for this experiment is same as used for Experiment 74.

In performing this experiment and writing up same, follow directions outlined under Experiment 74.

Experiment No. 76

TEST OF RIVETED JOINTS

This test is necessarily a test of the material from which the riveted joint is made, rather than a test of the joint itself, it being impractical to test the efficiency of the joint itself under working conditions.

Experiment No. 77

TEST OF STEEL AND IRON FORGED JOINTS

Sample forged joints are tested and the strength of these compared with the strength of the unwelded material.

Experiment No. 78

TEST OF FIBRE AND COTTON ROPE

This test is made in a testing machine and is a comparative tensile test.

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EXPERIMENT No. 79

TEST OF STEEL, IRON, AND MUSIC WIRE

Same as Experiment No. 78.

EXPERIMENT No. 80

TEST OF COLD ROLLED STEEL SHAFTING

This test is designed to determine if "cold rolling" the surface adds to the strength of the shaft.

Test pieces of cold rolled shafting in torsion testing machine and compare the results with the results of tests of turned shafting of same material.

In connection with this experiment, several key-ways cut into shaft will show how size of key-ways must be considered in the design of shafting for strength.

Testing the strength of keys and set screws may be included in this experiment.

EXPERIMENT No. 81

STRENGTH OF MACHINE FRAMES

The machine frame that is taken up in this investigation is a cast iron or steel frame of a punching machine. The theory and discussion is taken up in the classroom and will be omitted here.

The frame to be tested should be measured and the cross sections computed, that is, the design of the frame should be carefully checked by the student before the frame is actually tested.

Similar investigations are described in *Elements of Machine Design*, by Benjamin and Hoffman. See also article by A. L. Jenkins in *A. S. M. E. Proceedings* of July, 1910.
Elements of Machine Design, by Kimball and Barr, gives a treatise on this type of frame.

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